A COMPARATIVE STUDY OF TEMPERATURE FLUCTUATIONS IN DIFFERENT PARTS OF THE HUMAN BODY

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FRANCIS G. BENEDICT AND EDGAR P. SLACK

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A COMPARATIVE STUDY OF TEMPERATURE FLUCTUATIONS IN DIFFERENT PARTS OF THE HUMAN BODY.

PART I.—INTRODUCTION.

The normal body-temperature is a resultant of two factors, thermogenesis, or the development of heat inside the body; and thermolysis, the loss of heat from the body. Usually these two factors are so delicately adjusted as to be nearly equal in value and hence the resulting temperature of the body does not alter materially. When there are marked disturbances in either factor, we have changes in body-temperature. Innumerable experiments[1] have been made to investigate the factors influencing both thermogenesis and thermolysis, and it has been proved that the most important factor affecting thermogenesis is muscular work, either voluntary or involuntary, while the most important factor affecting thermolysis is the temperature environment; this latter is particularly true of small animals.

A knowledge of the fluctuations in body-temperature is of inestimable value to the physician as an index of the body condition; in health the normal limits are rarely exceeded, and consequently increased temperature indicates that radical measures must be taken. To the physiologist, also, a knowledge of the course of the normal body-temperature is important, and when experiments on calorimetry are attempted this factor has especial significance.

HEAT PRODUCTION.

By means of modern apparatus, an accurate measurement may now be made of the total heat given off from the body of a man during an experimental period by the three paths of conduction, radiation, and the latent heat of water vaporized. This of itself is an important contribution to physiology, but of still greater importance is the measurement of the total heat production. The heat production may or may not be the same as the heat elimination, since any discrepancy between thermogenesis and thermolysis causes a change in body-temperature resulting in the loss of a certain amount of heat previously stored, or the storage of heat to be subsequently eliminated. This may be shown by a simple calculation:

From the results of a large number of experiments, a standard value for heat production has been computed for a man weighing 66.6 kilograms, while at rest and asleep.[2] Owing to its large content of water, the body has the

[1] A historical development of the study of body-temperature, including methods, is given in the excellent article by Pembrey in Schaefer's Textbook of Physiology, vol. 1, 1898, p. 785. This article also includes an extensive statement of literature up to the date of publication.

[2] Benedict and Carpenter, Pub. No. 126, Carnegie Institution of Washington, 1910, p. 253.

somewhat high specific heat of approximately 0.83;[1] the body of a man weighing 66.6 kilograms would consequently have a hydrothermal equivalent of about 55 kilograms of water, so that a change in its temperature of 0.1° C. would produce either a storage or a loss of 5.5 calories of heat. According to the standard value which has been computed, the heat production of a man of this weight and under these conditions would be 71 calories; consequently the amount of heat absorbed or given up by the body as a result of the change in temperature of 0.1° C., *i. e.*, 5.5 calories per hour, would be approximately 7.7 per cent of the total. This discrepancy is too great to permit the measurement of the heat elimination to be taken as an index of the heat production.

Practical experience has shown that a change in temperature amounting to 0.1° C. is very likely to occur, even with enforced body quiet and rest; as a matter of fact, a normal variation in temperature amounting to 1.5° C. is easily possible in a period of 24 hours. If, as is wholly unlikely, such a large variation as 1.5° C. should take place in a shorter experimental period as, for instance, 1 hour, there would be, under the conditions previously cited, a liberation or storage of heat of 82.5 calories. If this heat were stored instead of being eliminated, it is quite conceivable that during the 1-hour period the body would produce heat at such a rate as to raise its temperature 1.5° C., with the elimination of absolutely no heat. While such conditions are physiologically impossible in so short a period, yet when physiologists are attempting to measure the heat production for periods of 1 hour or less a knowledge of even slight variations in body-temperature is of great importance.

The determination of the fluctuations in body-temperature in 24-hour respiration calorimeter experiments is not of particular importance, since one would expect to find approximately the same body-temperature at approximately the same hour of the day; thus, all of the earlier experiments published by Atwater and Benedict[2] were planned on the assumption that at 7 o'clock in the morning (the end of the 24-hour period) the body composition of a subject existing on a uniform diet was constant from day to day, and the body-temperature returned to essentially the same level at this time. When the attempt is made, however, to shorten the experimental periods to 8 hours, 6 hours, 2 hours, or even less, an exact knowledge of the body-temperature at the beginning and end of each period becomes of more and more importance. By means of respiration calorimeters,[3] it is now perfectly feasible to measure the chemical factors of metabolism, namely, the carbon dioxide excretion, oxygen consumption, and water vaporization, in periods of 1 hour; indeed, in the past few months, experimental periods of three-quarters of an hour have been successfully carried out and made a part of the regular routine of this laboratory. The heat eliminated can be likewise measured, and it remains only to make an accurate measurement of the body-temperature to secure the data for computing with considerable exactness the heat production during these periods.

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[1]Pembrey, loc. cit., p. 839.
[2]Atwater and Benedict, U. S. Dept. Agri., Office Exper. Sta., Bull. 136, 1903.
[3]Benedict, Riche and Emmes, Am. Journ. Physiol., 1910, **26**, p. 1.

DIRECT AND INDIRECT CALORIMETRY.

The data regarding the heat production in short periods are especially valuable in demonstrating the accuracy of so-called indirect calorimetry as compared with direct calorimetry—a demonstration which is of great theoretical as well as practical importance. Such a comparison has been repeatedly made for periods of 24 hours[1] by Atwater and associates, and while the methods of these investigators differ somewhat from those used by Zuntz, it has been shown conclusively that indirect calorimetry for periods of this length is extremely accurate. This demonstration, however, is of little practical value. In the first place, in relatively few instances is the total carbon dioxide excretion for 24 hours determined from which the heat production can be calculated. Secondly, it is extremely rare that the total oxygen consumption for this period is determined. Practically all of the computations made by the Zuntz school have been based upon experiments of 15 to 40 minutes' duration. It becomes, therefore, of fundamental importance to demonstrate the relationship between the gaseous exchange and the heat production not only in periods of 24 hours but in short periods, also.

The calculation of the total metabolism from the data regarding the nitrogen excretion, the carbon-dioxide excretion, and the oxygen consumption assumes that the nitrogen and the carbon dioxide excreted and the oxygen consumed during a given period represent direct molecular transformations which resulted in an energy transformation during that period; that is, that there was no material delay in the oxidative processes; that there was no accumulation of either oxygen or carbon dioxide in the system; and that the nitrogen corresponded to the protein broken down during the period under investigation. Considerable criticism has been made of this method of calculation, but in all probability, if proper precautions are taken to secure constant conditions of diet for a sufficiently long period beforehand, there will be a general uniformity in metabolism; and while the metabolism actually measured in any hour period, as for instance, between 8 and 9 a. m., may not represent the exact transformation during the period, nevertheless it does represent a certain definite average transformation which is approximately accurate. Until, however, it has been clearly demonstrated that indirect and direct calorimetry agree even for short periods, we can place no absolute dependence upon observations and calculations based upon indirect calorimetry.

PURPOSE OF THE RESEARCH.

To sum up, then, it is possible for us to measure with great accuracy the carbon-dioxide excretion, oxygen consumption, water vaporization, and nitrogen excretion during any given experimental period. We can likewise measure with considerable accuracy the heat eliminated by radiation, by conduction, and in the latent heat of water vaporized. On the other hand, we find great

[1]Atwater and Benedict, loc. cit.; also Benedict and Milner, U. S. Dept. Agri., Office of Exper. Sta., Bull. 175, 1907.

difficulty in computing exactly the heat production, since this is dependent upon an accurate measure of the body-temperature. In any method of measurement thus far devised, the important assumption must be made that the human body as a whole undergoes an average change in temperature corresponding to the fluctuations found by measuring the temperature of any one portion of the body. This last assumption has been based on such uncertain evidence up to the present, that it has seemed desirable to investigate more carefully the fluctuations in temperature of the different parts of the body.

In taking up this problem, we were at once confronted with two rather important questions: First, where is the best place to take the temperature of the body; and second, are the fluctuations in temperature uniform throughout the body? Certain reasoning might here be brought forward to prove that the blood, being a great distributor of heat, equalizes the temperature throughout the whole body, so that we should expect the temperature changes in the different parts to follow a parallel course. If all parts of the body were of essentially the same temperature, this might be easily assumed without question; as a matter of fact, the temperature is not uniform, there being, as one would naturally expect, a sharp thermal gradient. The accurate measurement of the surface temperature presents many difficulties, but as a result of numerous observations made by different methods, 32° C. has been commonly accepted as a standard, and is probably not far from the true value. The temperature inside the body, on the other hand, is known to be not far from 37° C.; we have here, therefore, a gradient of 5° C. This gradient should be very carefully studied before assuming that the temperature in different parts of the body remains constant throughout the whole series of experiments. If the source of heat is constant, as evidenced by the interior temperature of the body, and the temperature of the environment does not change, there is every reason for believing it probable that the gradient will be constant.

Accordingly, in this particular research we have made a simultaneous study of body-temperature, with reference to determining: (1) the best place for an accurate and constant measurement of body-temperature; (2) the temperature gradient of the body; and especially (3) whether or not the temperature fluctuations occurring in the different parts of the body are uniform.

LOCALITIES FOR TEMPERATURE MEASUREMENT.

NATURAL CAVITIES.

A physical examination of the body shows that there are a number of natural cavities which provide favorable opportunity for measuring the body-temperature, since they are surrounded by living tissue and not subjected to the immediate effects of the external environmental temperatures. Of these cavities, by common consent of practically all physiologists, the rectum is considered to be the most favorable and to indicate the truest temperature of the interior of the body. Its use, however, is practicable only in experiments with patients who are bed-ridden and in physiological tests. With female

subjects under similar conditions, the vagina is also an admirable place for making temperature observations.

Rectum.—In taking the temperature in the rectum, it is of prime importance first to note that the thermometer should not be imbedded in fecal matter, as otherwise there may be a sluggishness in the records. This is particularly necessary with glass clinical thermometers, which are sufficiently rigid to become easily imbedded in a mass of fecal matter. Again, the thermometer must be inserted deep enough in the rectum to make sure that the record is not affected by the temperature of the outside air. This latter point will receive special consideration later.

Mouth.—In the private practice of a physician, the rectum and the vagina are practically precluded in the majority of instances and recourse is had to taking the temperature in the mouth. While it is true that the cavity in the mouth underneath the tongue is surrounded by living tissue and protected, at least in part, from the external environmental temperature, nevertheless the cold air from the nasal passages, the frequent breathing through the mouth, and the rapid vaporization of water by the relatively dry air entering the mouth usually produce a supercooling of this cavity. This supercooling may be very noticeable, particularly after severe exercise.[1]

Stomach.—The stomach has been rarely used in measuring body-temperature, since it is somewhat difficult for subjects to swallow a stomach tube with any degree of comfort. While there are relatively few instances in which a fistula has been employed for such measurements, a most interesting series of observations has been made on the temperature in the stomach during digestion, beginning with the early experiments of William Beaumont[2] on Alexis St. Martin, and continuing with the more recent experiments of Rancken and Tigerstedt.[3] Under ordinary conditions, however, it is practically impossible to measure the temperature in this way.

Bladder.—So far as we know, no records of the body-temperature have been taken in the bladder by means of a thermometer inserted through a catheter; nevertheless, mention should be made of the extremely ingenious method first suggested by Stephen Hales[4] of measuring the temperature of freshly voided urine which represents very nearly the temperature of the interior of the body. In such observations it is evident that the time during which the temperature can be taken is relatively short, depending upon the volume of urine passed. Furthermore, the thermometers used should be very sensitive and should first be warmed by the hand or in the mouth to nearly the temperature of the body before placing the bulb in the stream of urine.

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[1]Williams and Arnold: Phila. Med. Journ., **3**, p. 1233.

[2]Beaumont, Experiments and observations on the gastric juice and the physiology of digestion, Plattsburgh, 1833.

[3]Rancken and Tigerstedt, Biochem. Zeitsch., 1908, **11**, p. 36.

[4]Hales, Statical Essays, London, 1731, 2d ed., **1**, p. 59.

ARTIFICIAL CAVITIES.

Axilla.—In addition to the natural cavities of the body, there are certain artificial cavities which can be formed by a movement of the limbs, or the folds of the skin, the most important being the axilla. In the normal position of the arm, the axilla provides a natural cavity which needs only to be carefully closed in order to approximate an interior cavity of the body. The axilla is, however, for a good part of the time exposed to a temperature environment not far from 32° C., *i. e.*, the surface temperature of the body, instead of 37° C., that of the interior of the body. The presence of moisture, sweat glands, and hair all combine to make this cavity somewhat difficult to use.

Groin.—Another locality which has been found of great value is the groin. Particularly is this useful in taking the temperature of small infants when clinical thermometers can not be used in either the mouth or the rectum for fear of breakage. Unless subjects are emaciated, it may also be used very satisfactorily with adults after the cavity has become warmed to the temperature of the body.

Other cavities.—Other artificially prepared cavities may be secured by crossing the legs, the temperature being taken inside of the thighs; and by holding the thermometer between the two hands, and obtaining the temperature of the palms. These cavities, however, are not generally used for measuring the body-temperature in either medical practice or physiological experimenting.

SURFACE TEMPERATURE.

The temperature of the exposed surface of the body can be taken at any point, but, as has already been stated, such observations present many difficulties. Any form of thermometer that may be used is not only subject to the temperature of the body, but also to that of the cooler outside environment; and while this discrepancy may be somewhat lessened by artificial warming, such measures are at best unsatisfactory and inaccurate. Again, if the thermometer is firmly fastened to the body, there is liable to be a local congestion, especially if the area of the thermometer is large, and the functions of the sweat glands, both underneath the thermometer and in its immediate vicinity, may be somewhat disturbed.

BASE-LINE IN MEASURING BODY-TEMPERATURE.

An examination of these different possibilities or localities for taking the temperature of the body shows immediately that those least affected by environmental changes are the natural cavities in the body, *i. e.*, the rectum, the vagina, and the mouth, the records obtained in the rectum being commonly considered the best suited as a base-line for all observations.

ERRORS IN RECTAL-TEMPERATURE MEASUREMENT.

In thus using the rectal-temperature as the base-line, it is necessary to take into consideration the possible errors affecting the measurements made in the

rectum. First, as has already been pointed out, the thermometer should not be inserted in the fecal mass. If there is any danger of this, the fecal matter should be removed by a water enema; also, sufficient time should elapse between the taking of the enema and the beginning of the temperature observations to make sure that the change in the local temperature produced by the water is not affecting the temperature of the rectum. Second, the thermometer must be inserted sufficiently deep to give the maximum temperature, the depth required being readily found by testing, and noting the point at which the maximum temperature occurs. If the thermometer is constructed of non-irritating material, there is very little liability of any local congestion. The experience of observers with glass mercurial thermometers has led to some difficulty in securing long-needed observations of body-temperature, owing to the rigid construction of the thermometers, but with the flexible thermometer employed by Benedict and Snell[1] continuous observations can be readily made in periods of several days, the thermometer being removed only for defecation. It seems well established, therefore, that with a proper construction of the thermometer the fear of local congestion may be entirely eliminated.

CONSTANCY OF RECTAL-TEMPERATURE.

If the rectal-temperature is to be used as the base-line, it is natural to assume that there should also be a more or less constant temperature which should be taken as the base-line, and we can properly question whether or not the rectal-temperature is sufficiently constant for this purpose. Obviously the temperatures which are markedly above the average of a large number of observations may be taken as indicating fever and should not be used as a base-line. On the other hand, there may be a fluctuation in the normal temperature amounting to 1.5° C., and any fluctuations within this limit may be reasonably taken as normal for the individual under experimentation. Before assuming that the observations of the rectal-temperature represent a normal value for the individual, however, we should examine carefully to find what factors affect the body-temperature.

FACTORS AFFECTING BODY-TEMPERATURE.

Exposure to severe cold lowers the temperature, provided there is no shivering incidental to an attempt on the part of the body to compensate for the excessive heat lost. The ingestion of hot or cold food and drink, likewise muscular work, produces an almost immediate effect. In connection with muscular work, it is important to note that there may be not only internal, but also external muscular work; consequently, for the strictest comparison, the temperature of the subject should be measured under constant conditions of muscular activity, ingestion of food, etc.

Furthermore, it has long been known among physiologists that there is a rhythm or periodicity in the temperature of the body. By experiment, it has

[1]Benedict and Snell, Archiv f. d. ges. Physiol., 1901, 88, p. 492.

been found that this rhythm is somewhat as follows: The minimum temperature occurs during the early morning hours, usually between 2 and 5 o'clock; there is then a marked early morning rise which becomes less pronounced as the day progresses, but reaches its maximum in the afternoon about 5 o'clock; this is followed by a slight fall, which becomes very noticeable after retiring and gradually continues until the minimum point is again reached in the early morning.

A number of attempts have been made to explain this rhythm, which as yet have been only partially successful, although the rhythm appears to be more or less coincident with the muscular activity incidental to the day's work. This explanation is not scientifically complete, however, for it does not explain why a night watchman,[1] who for seven years had been working during the night and sleeping in the daytime, should still have the highest body-temperature at 4 or 5 o'clock in the afternoon when he was sound asleep, and the lowest value at 4 or 5 o'clock in the morning when he was awake and on his rounds. Daylight and cosmic influences have also been thought to have an effect upon this rhythm. It is not the object of this report, however, to enter into a discussion of the cause of the normal periodicity or rhythm, but in any study of body-temperature this factor should be taken into consideration when endeavoring to establish a base-line. For the particular reason for which this investigation was undertaken, namely, to study simultaneously the temperature fluctuations in different parts of the body in order to find whether or not they paralleled each other, the absolute temperature values at any given point are not of such great importance as are the variations. Consequently we may assume that previous experiments have demonstrated clearly the existence of a rhythm and have likewise demonstrated the difficulty of giving a satisfactory explanation which covers all observations thus far made.

Johansson's belief[2] that the body-temperature is influenced in large part by the metabolism is strongly substantiated by his observations, and yet it is difficult to conceive that the night watchman previously referred to had a higher metabolism during the periods when he was sound asleep than when he was sitting up in a chair engaged in conversation. From the well-known relationship between the pulse-rate and the metabolism, it is clear that all future experiments on body-temperature should be accompanied by a simultaneous observation of the pulse-rate and, so far as possible, of the metabolism and its changes. In the majority of experiments, observations of the metabolism will be impossible, but records of the pulse-rate may be easily obtained by practically all observers. If to these observations can be added others with regard to the blood pressure and pulse pressure, the results will be still more valuable, especially in throwing light upon the contention of Johansson that the body-temperature is a function of the total metabolism.

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[1]Benedict, Am. Journ. Physiol., 1904, 11, p. 145.
[2]Johansson, Skand. Archiv f. Physiol., 1896, 7, p. 123.

Part II.—Methods and Apparatus.

An analysis of the measurements to be made as outlined in the preceding section shows that the method of measurement must comply with the following requirements:

Several temperatures must be observed at practically the same time, and this process repeated at intervals of a few minutes for protracted periods.

The precision of the measurement must approximate 0.01° C.

The thermometers must be capable of being read without being disturbed; they must also be small and flexible, so as not to cause undue discomfort even if in position for a considerable length of time.

Only two methods were considered as being able to meet these conditions, namely, those employing (1) electrical resistance thermometers,[1] and (2) electrical thermal-junction thermometers.[2]

COMPARISON OF METHODS.

The many advantages of the resistance method have led to its extended application. In the first place, it has inherently a greater sensitiveness than can be obtained by the thermal-junction method. The reason for this might be suggested by the fact that in the resistance method the amount of energy expended in the thermometer is left entirely to the discretion of the designer, while in the thermal-junction method the source of energy is in the thermometer itself and therefore is limited by the physical properties of the junction. This implies, also, that the electromotive forces involved in the resistance method will, in general, be far greater than those used in measurement with the thermal junction, so that with the resistance method comparatively little trouble will be experienced from extraneous electromotive forces, which are so common a source of annoyance in thermo-electric measurements. Another advantage of the resistance method is that the measurement is completed by performing a single operation, usually that of balancing a bridge; there is no second temperature to be read, no potentiometer current to be adjusted, and no routine observations necessary to correct for the effect of extraneous electromotive forces. Also, the apparatus for measuring the temperature of the resistance thermometer is simpler than that required for the thermal junction, as in the former case no constant temperature need be maintained, also no standard cell is necessary.

In spite of these manifest advantages, there are certain qualities inherent in the resistance method which make it less fitted than the thermal-junction method for meeting the requirements previously outlined. For example, the measuring current flowing through the resistance thermometer produces an appreciable heating of the wire, the resistance of which is being measured. In measurements with the thermal junction, however, the current taken from

[1]Benedict and Snell, Archiv f. d. ges. Physiol., 1901, **88**, p. 492; and 1902, **90**, p. 33.
[2]Gamgee, Phil. Trans. Royal Soc. of London, Ser. B., 1908, **200**, p. 219.

he junction for the purpose of deflecting a galvanometer would be very slight, so that the heating—which depends on the square of the current—would be very small indeed. Furthermore, a method may be used which does not involve drawing current from the junction, and thus the error may be entirely avoided.

Again, the resistance thermometer, as usually constructed for body-temperature measurement, consists of a coil of fine wire, inclosed in a metal shell. This construction is necessarily bulky, owing to the fact that a considerable quantity of wire must be used. Moreover, the mass of the thermometer is large, giving more or less lag, and its construction is relatively very difficult. The thermal-junction thermometer, on the other hand, in its simplest but thoroughly practical form, consists merely of a twisted and soldered joint between two fine wires, one of which is insulated, both wires being protected from moisture and mechanical injury by an outside case of thin-walled rubber tubing. It will thus be seen that the thermometer is small and flexible, which not only permits its ready introduction into the deep natural cavities of the body, but also allows it to be covered easily by flesh when used in the shallow artificial cavities; furthermore, its small mass precludes any appreciable lag.

A third disadvantage of the resistance method is that, in the type of thermometer commonly used for body-temperature measurement, the resistance itself is not in very good thermal contact with the body whose temperature is being taken, whereas the thermal connection between the thermal-junction thermometer and the body may be made absolutely ideal. Since no theoretical demands will be violated if one of the metals of the junction actually touches the body being measured, the junction may be made in the form of a wire of one of the metals soldered to the back of a thin plate or cap of the other and the face of this latter applied directly to the body; in this way the active material of the thermometer may touch the body without even the thinnest layer of isolating material.

A careful comparison of the advantages and disadvantages of these two methods, considered only in the light of the requirements of these special experiments and not at all with regard to temperature measurements in general, led to the adoption of the thermal-junction method, and this in spite of our previous extended use of the resistance thermometer for body-temperature measurements. The sensitiveness was considered ample, and the disadvantages of the occasional observations necessary in reading a second temperature, balancing current, and correcting for stray voltage were regarded as being more than offset by the freedom from heating and the ability to use thermometers which were at once small, simple, flexible, and strong. The thermal-junction method has the still further advantage that the thermometers are practically interchangeable without adjustment.

THEORY OF METHOD OF MEASUREMENT USED.

The thermal-junction method is based upon the well-known principle that if a junction of two dissimilar metals be heated, a difference of potential between the two will result; and if the circuit be closed through a galvanometer, a current will be produced and the galvanometer deflected. In order that small temperature fluctuations may be measured with precision, use is made of a second junction in series with and opposed to the first, this second junction being kept at a constant known temperature somewhere in the region of the temperature to be measured. By this means the net electromotive force is made very small, so that slight changes due to fluctuations of the unknown temperature form a large percentage of the whole. The use of deflections in this way, although convenient and simple, has one disadvantage, in that the resistance of the galvanometer and conducting wires must be taken into account, since a change in the circuit resistance would cause an inversely proportional change in the deflection. With the apparatus used in these body-temperature experiments, a fluctuation of more than 1.2° C. in the galvanometer temperature would not have been allowable. Moreover, the effective voltage at the galvanometer terminals, being the voltage of the thermal-junction system minus the fall in potential along the wires, would have been reduced to about 75 per cent of its total value.

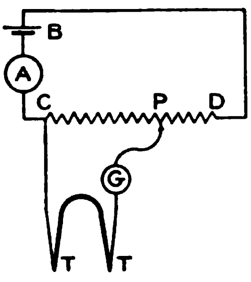


FIG. 1. Elementary wiring diagram of apparatus. Current from the battery B flows through the slide wire DC and returns to the battery through the ammeter A. The thermal-junction system TT, with the galvanometer G, is connected at one end to C, and at the other to a movable contact which may be touched at any point along the slide wire.

These conditions, although not prohibitive, were nevertheless regarded as undesirable, so that a "null" method, by means of which they were entirely avoided, was finally decided upon. This "null" or "zero" method is a modification of the ordinary potentiometer method for the measurement of electromotive forces, and consists in balancing the electromotive force of the thermal-junction system against the fall in potential across a section of a standardized slide wire in which a known current is maintained. An elementary diagram of connections is shown in fig. 1. The battery B sends a current through the circuit B-D-C-A-B, the value of the current being measured by the ammeter A. CD is a uniform slide wire of known resistance, to one end of which, as at C, is attached one end of the thermal-junction system TT. The other end of the thermal-junction system is connected through the galvanometer G to a movable contact which may be touched at various points along the slide wire until a point P is found at which no galvanometer deflection results. The voltage of the thermal-junction system can then be calculated, if desired, this being the product of the current expressed in amperes and the resistance CP expressed in ohms. The voltage of the system is, however, usually of secondary importance; what is desired is the tempera-

ture difference between the two junctions. This might be assumed to be approximately proportional to the voltage, but can be obtained directly by keeping both junctions at known temperatures; in this way the apparatus can be calibrated so that different settings of the contact correspond to definite values of the temperature difference being measured. In order to make the apparatus direct reading, an additional resistance in series with the battery is almost universally used and the current is so adjusted as to accommodate itself to the particular slide-wire available. By bringing the current to such a value that the fall in potential across one division of C–D is equal to the voltage of the thermal-junction system for a temperature difference of 0.01° C., the apparatus becomes practically direct reading in hundredths of a degree.

ADAPTATION OF METHOD FOR USE.

The actual arrangement, as shown in fig. 2 (p. 15), does not differ in principle from this. The storage battery B, which has been partly discharged in order to obtain a more nearly constant voltage, sends current continuously through the circuit B–R–V_1–V_2–V_3–V_4–S in parallel with P–M–B. The resistance R is fixed, and is placed in the circuit for the purpose of bringing the current to such a value that the apparatus is practically direct reading; V_1, V_2, V_3, and V_4 are variable resistances by means of which the current can be maintained constant in spite of slight changes in the electromotive force of the storage cell, such as might be caused by a gradual discharging of the cell, temperature changes, etc. The shunt S is placed across the potentiometer P on account of the extremely low voltages to be measured. The resistance M is so arranged that the standard cell N and galvanometer G can be closed across it, this arrangement forming the equivalent of a very accurate ammeter, so precise that a high resistance O is introduced into its circuit to reduce the sensitiveness. Since the galvanometer must be used in connection with both the standard cell and the thermal-junction circuits, the switches G_1 and G_2 are provided for transferring it from one to the other. By means of the test switch T, the apparatus may be tested for stray electromotive forces. The control switch K is used for convenience in bringing the galvanometer to rest. The switches 1, 2, 3, 4, etc., are also provided so that the electromotive force of any one of a number of thermal-junction systems may be measured. To each of these switches are connected two copper wires, one of which runs to the body and the other to a constant-temperature bath, these latter terminals being connected by a constantan wire, which furnishes the second metal for the thermal junctions.

APPARATUS USED IN THE RESEARCH.

CONSTANTS OF THE APPARATUS.

While considering the measurement from a purely theoretical standpoint, and before proceeding to a description of the actual construction, it may be well to bring together the constants of such parts of the apparatus as were available for the work, and to include the computations by means of which

the remaining constants were derived and the suitability of the apparatus for the work assured.

The potentiometer has a resistance of 15,000 ohms, which can be included between the potential terminals in steps of 0.1 ohm. The galvanometer resistance is about 50 ohms, and the sensitiveness such that a deflection of 0.5 millimeter is produced by a current of 15×10^{-10} amperes. The resistance of the constantan wire as selected is about 14 ohms for each circuit; that of the copper is negligible. The electromotive force of the copper-constantan couple is taken as 40×10^{-6} volts per degree centigrade. The voltage of the storage cell is 2.0 volts, that of the standard cell 1.0197 volts. Most of the temperatures to be measured are assumed to lie within the limits of 36° to 38° C., and are desired to an accuracy of about 0.01° C. The apparatus, however, should not be restricted to these limits but should be capable of measuring lower temperatures, although with a somewhat decreased precision.

The constant-temperature junction is kept at a temperature of about 40° C., and as the other junction never rises to so high a temperature as this, it follows that the net voltage of the thermal-junction system always acts in one direction. The temperature difference between the junctions is usually not less than 2° C. nor greater than 4° C., so that under these circumstances the voltage limits would be 80×10^{-6} volts and 160×10^{-6} volts, between which the voltage should be determined to approximately 0.4×10^{-6} volts.

The necessity for a potentiometer shunt may be very easily shown. If the apparatus is to be direct reading—a change of 0.4×10^{-6} volts involving a change of 0.1 ohm in the potentiometer setting—then a current of $(0.4 \times 10^{-6}) \div 0.1$, or 4×10^{-6} ampere is required, and this, if a regular series circuit is used, demands the use of a circuit resistance of $2 \div (4 \times 10^{-6})$ or 500,000 ohms. Since this is hardly practicable, it has been decided to shunt the potentiometer, leaving the current in the potentiometer itself 4×10^{-6} ampere, but taking from the storage battery about 0.01 ampere, and causing the remainder to flow through the shunt. For the main current a value of 0.0102 ampere has been decided upon, as this permits the use at M of a 100-ohm coil. The value of S is then $(4 \times 10^{-6} \times 15000) \div (0.0102) = 5.88$ ohms. The total resistance of the circuit is $2.0 \div 0.0102$ or 196 ohms, 100 ohms being taken by M and about 6 ohms by S in parallel with P, leaving still 90 ohms necessary to be taken up in R, V_1, V_2, V_3, and V_4.

To determine the proper value for each step of the variable resistances, it must be noted that while voltages as high as 160×10^{-6} volts are to be measured, yet a deviation of 0.2×10^{-6} volts will in itself produce an error in the results sufficient to affect the nearest hundredth of a degree. From this it is seen that the current must not vary by 2 parts in 1600, so that each step in the variable resistances must not make more than this fractional change in the resistance, or $(2 \div 1600) \times 196 = 0.25$ ohm. This represents the maximum allowable change; consequently the steps in the resistance as actually made are smaller than this. The smallest steps are in the resistance V_3, which is composed of nine 0.1 ohm coils. Similarly V_4 comprises nine 1.0 ohm coils, so

that the combination gives a resistance of about 10 ohms, variable in tenths of ohms. V_1 and V_2 are provided should even more adjustment be necessary, and have a resistance of 5 ohms each. This gives 20 ohms for the sum of the variable resistances, about half of which should be in circuit under normal conditions, so as to allow adjustment in either direction. The value for R is accordingly $90-(20\div 2)=80$ ohms.

To determine whether the galvanometer is sufficiently sensitive, it will be simplest to consider the case of a measurement being made in which the circuit is not quite balanced, but owing to the insensitiveness of the galvanometer it appears to be so. The largest current that can pass through the galvanometer and still be undetected is 15×10^{-10} amperes. This current in flowing through a resistance of 64 ohms, composed of the galvanometer and thermal-junction system, causes a fall in potential of $15 \times 10^{-10} \times 64$ or about 10^{-7} volts. Since 0.01° C. corresponds to 0.4×10^{-6} volts, or 4×10^{-7} volts, it is seen that the error due to insensitiveness of the galvanometer corresponds to about 0.0025° C. and is therefore entirely negligible.

CONSTRUCTION OF THE APPARATUS.

Having determined the constants, or electrical dimensions, of the various pieces of apparatus considered in fig. 2, the actual method of construction and installation will be given in some detail. This seems advisable, since in some cases the peculiar experimental conditions to be met required a special form of construction; while in other cases some of the more elaborate pieces of apparatus available, which were not ideally adapted to the work, have been made to conform more closely to the desired qualifications.

MEASURING INSTRUMENTS.

Storage cell.—The storage cell B is one of a battery of six cells, having a normal rate of three-quarters of an ampere and provided with separate terminals for each individual cell. A suitable resistance, not shown in fig. 2, is arranged so that it can be connected across the battery when desired. The separate terminals permit each cell to be used singly, and the resistance is used partially to discharge the battery when freshly charged, thus causing its voltage to be more nearly constant.

Both the storage cell and the standard cell are provided with reversing switches, which are mounted on a single base and arranged so as to be operated together by means of one handle. This is done for the following reason: The electromotive force of the thermal-junction system, standard cell, and storage cell must all act so as to have a tendency to send current through the main circuit in the same direction. For the purpose of keeping the voltage set up by the junction unidirectional, the temperature of the oven is always kept higher than that of the body. In order to provide for a possible decrease in the oven temperature, with a consequent reversal of this voltage, the storage cell and standard cell are furnished with the reversing switches just mentioned.

The resistances R, V_1, V_2, V_3, V_4, S, M, and O, as well as the coils in the potentiometer, are of manganin. V_1 and V_2 are each arranged to be short-

circuited by knife switches, while V_3 and V_4 are made up from two dial switches. The wires joining the main circuit to the shunted potentiometer are connected to the terminals of the shunt rather than to the terminals of the potentiometer, since the resistance of the latter is very large as compared with the former.

Potentiometer.—The potentiometer used is a combined potentiometer and Wheatstone bridge, made by Wolff.[1] In this type of instrument, the resist-

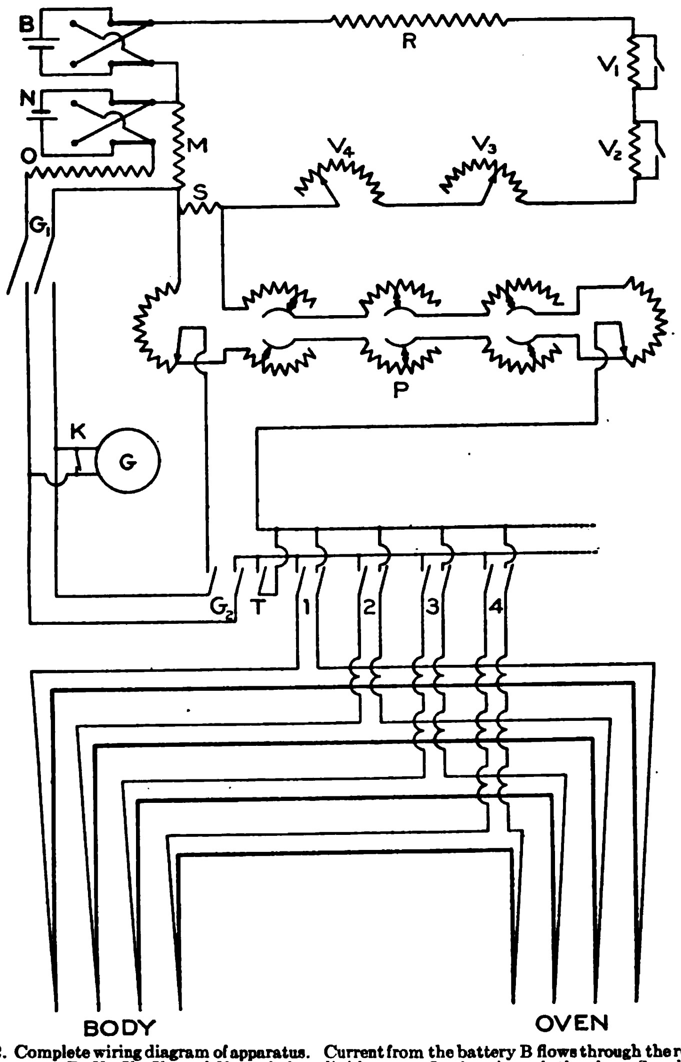


FIG. 2. Complete wiring diagram of apparatus. Current from the battery B flows through the resistances R, V_1, V_2, V_3, and V_4, and then divides, part flowing through the shunt S and part through the potentiometer P, the total current finally returning to B through the resistance M. The potentiometer, which is composed of 5 variable resistances is joined to the switching arrangement, of which G_2 connects the galvanometer G in circuit, T replaces the thermal-junction system when testing, and 1, 2, 3, 4, etc., are connected to the thermal-junctions at the body and the constant-temperature oven. The constantan wires are indicated by the heavy lines. N is the standard cell, protected by the high resistance O, and connected to the circuit through the double-contact key G_1. The switch K is for convenience in bringing the galvanometer to rest.

[1]Wolff, Zeitsch. f. Instrumentenkunde, 1903, Oktober.

ance is kept constant regardless of the position of the contacts by the device of two identical circuits, one of which is included between the sliding contacts while the other is not; these circuits being so arranged mechanically that as the resistance of one is decreased the resistance of the other is increased by the same amount. This arrangement has the disadvantage that contact resistance in the potentiometer circuit may affect not only the precision but also the accuracy of the measurement. In choosing apparatus for similar work, it should be noted that this is an unnecessary handicap, since the potentiometer may be so designed as not to require any contact in this very important part of the circuit. Also for thermo-electrical work, the potentiometer should have low resistance, so as to retain the full sensitiveness of the apparatus.

The potentiometer shunt is embedded in a block of paraffin, together with the brass binding posts of the potentiometer; also a similar block is used where the copper wires join the binding posts which are connected to the moving contacts. None of the knife switches G_2, T, 1, 2, 3, 4, etc., contain any junction of dissimilar metals, the circuit being copper throughout. Moreover, these switches are mounted at a distance of about 1 meter from the observer and are operated by means of long wooden rods. This construction is adopted in view of the fact that in some parts of the circuit, namely, in the potentiometer, the shunt, the switches just mentioned, the galvanometer, and the thermal-junction systems, it is very important to reduce as much as possible all stray electromotive forces.

The unavoidable junctions occur mostly in the form of reversed pairs; the paraffin blocks, by surrounding both these junctions with a medium having an appreciable mass, lessen the effect of transient fluctuations in the room temperature; furthermore, as these blocks have a greater heat-carrying capacity than air, they provide a better path for the transfer of heat between the two junctions, thus tending to equalize the temperature of the two. The slender wooden rods are used in connection with the switches as a further safeguard at these points to prevent heating from the hand.

Standard cell.—The resistance M is furnished in the usual way with both current- and potential-terminals. The standard cell N is a Weston Standard Cell, No. 1565, provided with the usual certificate stating its electromotive force. The following caution is expressed in the certificate: "To preserve the constancy of this cell, it should not be exposed to temperatures below 4° C., and no current greater than 0.0001 ampere should be passed through it." The insertion of the resistance O of 10,000 ohms assures the fulfilment of this latter requirement, and at the same time leaves an arrangement amply sensitive. The switch G_1 is in the form of a double-contact key, which remains open unless pressed, thus preventing the standard cell circuit from remaining closed accidentally.

Galvanometer.—The galvanometer is a reflecting instrument of the Deprez-d'Arsonval type, manufactured by Siemens & Halske. Among the advantages of this instrument might be mentioned first, that provision is made whereby

the whole moving system may easily be taken out and replaced by another, perhaps of different resistance or sensitiveness; second, that small windows are provided at the top and bottom of the suspension strip, by means of which it may easily be inspected or removed. The chief disadvantage for general work is, perhaps, that when the instrument is set up the moving coil is not visible and, the clearance being small, leveling becomes comparatively difficult. The resistance, 50 ohms, is rather too high for work of this character; probably a smaller resistance could have been used and still leave an instrument of sufficient sensitiveness. The galvanometer is not entirely free from thermal electromotive forces; indeed, this could hardly be the case where a number of metals are in circuit. This disturbing effect has been found to be less, however, in an instrument purchased in 1907 than in a later model purchased in 1909. With a view toward reducing extraneous electromotive forces in the galvanometer, it has been shielded as much as possible from temperature changes by placing over it a cork-lined wooden box. This is provided with a door at the side for inspection, leveling, etc., and with a transparent celluloid window in front through which the rays of light can pass. Since the use of a telescope for reading was regarded as too tiring for repeated observations, a ground-glass scale at a distance of almost 4 meters has been used, upon which the reflection of the filament of an incandescent lamp is focussed. If too long a scale distance should be used, in the attempt to increase the sensitiveness, a blurred image will result, caused by slight imperfections in the surface of the mirror.

The galvanometer has been mounted in the following way: A location was chosen near a structural steel upright on the street floor of the building and a strong shelf built out from the wall at this point. Upon the shelf was placed a square block of cork, 3 or 4 cm. thick, to which was fastened a 1.25 centimeter iron plate, and on this the galvanometer was mounted. The very slight vibration of the shelf resulting from the jar of the building is damped out by the cork, which acts as a spring.

The copper wires running to the thermal junctions have a diameter of 1.63 millimeters up to within 1 or 2 meters from the junction itself. At this point they are joined to smaller copper wires (0.455 millimeter), thus making the junctions smaller and more flexible. The wiring should be done in such a way as to leave no avoidable loops in the circuit; this will eliminate the inductive action of neighboring circuits, which otherwise might cause annoying deflections of the galvanometer.

THERMAL-JUNCTION SYSTEM.

Thermometers for internal temperatures.—Most of the junctions used for measuring temperature in the natural and artificial cavities of the body are simply twisted and soldered joints between two wires—one of constantan (0.455 millimeter) and the other of copper (0.455 millimeter). For taking internal temperatures a construction like A (fig. 3) is employed, in which the two wires run side by side, one of them being inclosed in a rubber tube for

insulation. The wires are then twisted and soldered together in the usual way, tied with silk, and finally covered with thin pure gum tubing. Before insulating the bare copper wire, however, the precaution is taken to protect it from the corrosive action of the sulphur in the rubber by "tinning" it or covering it with solder. It was found that the lag of the thermometer, due to the rubber tubing, was about 2.5 minutes;[1] this was regarded as being not too great.

For taking temperatures in the axilla a thermometer of the type illustrated under B, fig. 3, recommends itself. Here the joint is made by twisting and soldering two wires which approach each other from opposite directions, the inclosure in tubing being the same as before.

Another type of thermometer is shown in C, fig. 3. Here one of the metals of the junction touches the body without the intervention of any isolating material, so that the conditions for the taking up of the temperature by the thermometer are ideal. The copper element is made in the form of a very

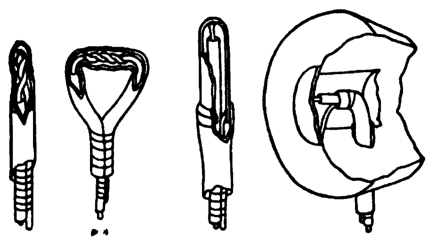


FIG. 3. Types of thermal-junction thermometers used. A, junction inclosed in rubber tube, used principally for internal measurements; B, same, arranged for use in axilla; C, junction in which one metal touches body, for taking internal temperatures; D, modification of this type for surface measurements.

thin hollow thimble, to the inside of which, at the end, is soldered the constantan wire, properly insulated. A copper wire soldered to the thimble completes the circuit. The connecting wires and the open end of the cap are covered by rubber tubing, and tied with silk, after which the copper is silver-plated. This arrangement fulfils the theoretical condition that both elements should not touch the skin, and at the same time provides an excellent thermal relation between the thermometer and the body whose temperature is being measured.

Thermometers for surface temperature.—The attempts made to obtain accurate measurements of the surface temperature were not successful, but a brief description of the thermometers used may be of interest. Several types of skin thermometers were constructed. At first the ordinary rubber-covered

[1]The method of testing the thermal-junction thermometers for lag was as follows: The thermometer being tested was connected to the measuring circuit and suddenly thrust into a flask of water at about body temperature. This caused a galvanometer deflection which at first changed rapidly but gradually became more nearly constant and finally could not be observed to change at all, the change in deflection corresponding to the change in temperature of the junction. The length of time noted above (2.5 minutes) is the interval elapsing from the instant when the thermometer was immersed until the deflection had become constant.

thermometers, A or B, fig. 3, were used, these being held in place by a bandage; afterwards they were pressed somewhat into the flesh by placing them under small pieces of wood which were strapped in position. A later type is shown in D, fig. 3. Here the general shape of the thermometer is along the lines finally used by Gamgee.[1] The support consists of a cork disk, somewhat rounded on the face. To this is shellacked a piece of thin sheet copper, shaped

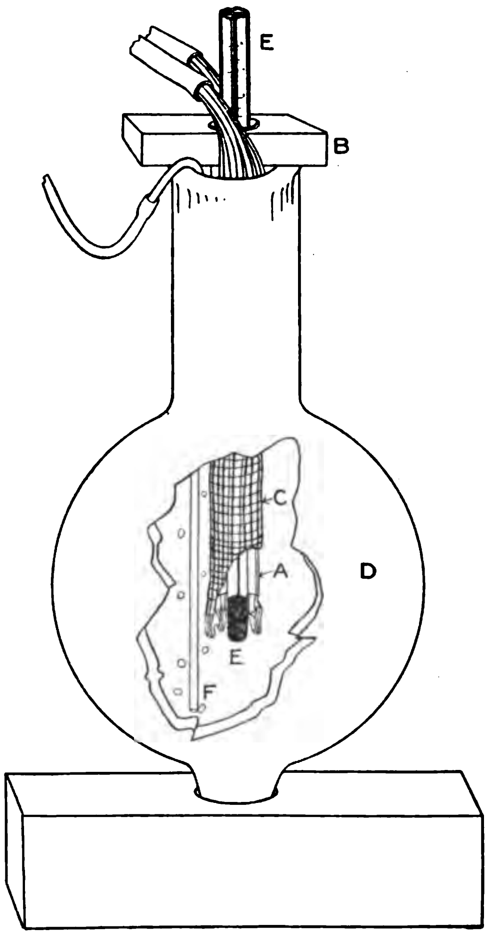


FIG. 4. Details of constant-temperature bath. The tube A, mounted in the block B, and inserted in a bath of warm water in the Dewar flask D, serves as a support for the thermal-junction wires C. The mercury thermometer E is inserted to the depth of the thermal-junctions. The water in the flask is stirred by compressed air entering through the tube F.

so as to bulge outward from the support. This copper plate furnishes one of the metals of the thermo-couple, a constantan wire soldered to the center of the back supplying the other, and a copper wire, also soldered to the plate, completing the circuit. The base is made of cork in order to give the apparatus a smaller mass, and the copper is shaped in the manner described so that it may

[1]Gamgee, loc. cit.

press into the flesh and take up the deeper temperature. The thermometer is held in place by a cloth strap. The junction itself must be shielded so that it may take up the body-temperature, and yet this must not interfere with the natural liberation of heat. These two conditions are incompatible, but the shape of thermometer chosen seems to fulfil both as well as possible.

Thermal junctions used in the constant-temperature bath.—The thermal junctions used in the constant-temperature bath are all made in the same way. The two small wires are slipped into separate capillary rubber tubes and a soldered joint made exactly as in type A (fig. 3) previously described. The different junctions are then supported in the following manner: A piece of glass tubing (A, fig. 4) is used, about 15 centimeters long and having a 16 millimeter bore. The upper end of this tube is passed through a block of wood B and secured with silk and shellac. Along the outside walls of the tube the thermal-junction wires C are laid, and firmly tied with silk in such a way as to leave the junctions protruding 1 or 2 centimeters from the bottom of the tube. The ends of the junctions are carefully separated, and the whole arrangement dipped in paraffin. The paraffined junctions, together with the glass tube, are then immersed in water contained in a large spherical Dewar vacuum flask D with silvered-glass, double walls. This flask has an outside diameter of about 15 centimeters, the distance between the walls being 8 millimeters, the length of the neck approximately 10 centimeters, and the capacity 1100 cubic centimeters.

A mercury thermometer, E, which indicates the temperature of the bath, passes through the tube A to such a depth that its bulb lies very near the thermal junctions and at the same level. This construction allows the thermometer to take up the temperature of the junctions very closely. The mercury thermometer is of the Beckmann type, having a range of 5° C., is graduated in hundredths of a degree, and calibrated by the Physikalisch-Technische Reichsanstalt. The true temperature, as obtained from the reading of such a thermometer, would be expressed by the formula $T=A+KR$, where T is the temperature desired, A being the zero reading of the thermometer, K a calibration constant which equals the true value of a scale division for the particular conditions of use, and R the reading.

CONSTANT-TEMPERATURE OVEN.

The flask D is placed in an oven, F (see fig. 5), in which the air is maintained at a constant temperature by the use of a mercury thermostat G which automatically supplies the proper amount of gas to a small burner H located beneath the oven. This oven, which is of sheet metal and about 33×40×50 centimeters, is inclosed in a slightly larger asbestos case with a sheet-metal bottom, the air space between the oven and the outside case being about 25 millimeters. The fronts of both are hinged; in the top are three holes, one for the insertion of the thermostat, one for the mercury thermometer E, and one for the insertion of the wires of the thermal-junction system. Through the last opening is also inserted a mercury thermometer for indicating roughly the

temperature of the air in the oven, and a tube for compressed air. By means of this tube compressed air, which has previously been passed through an indicator outside of the oven, is conducted into a bottle of water placed in the oven, and finally passes in a succession of bubbles up through the water in the Dewar flask itself.

By automatically keeping the air in the oven at the same temperature as the water in the flask, any small heat loss from the flask is avoided. The outer air-space and asbestos casing also aid in the temperature control of the oven, while the metal bottom assists in the equalization of the heat from the burner.

It was at first thought that, with the flask surrounded by ideal conditions,

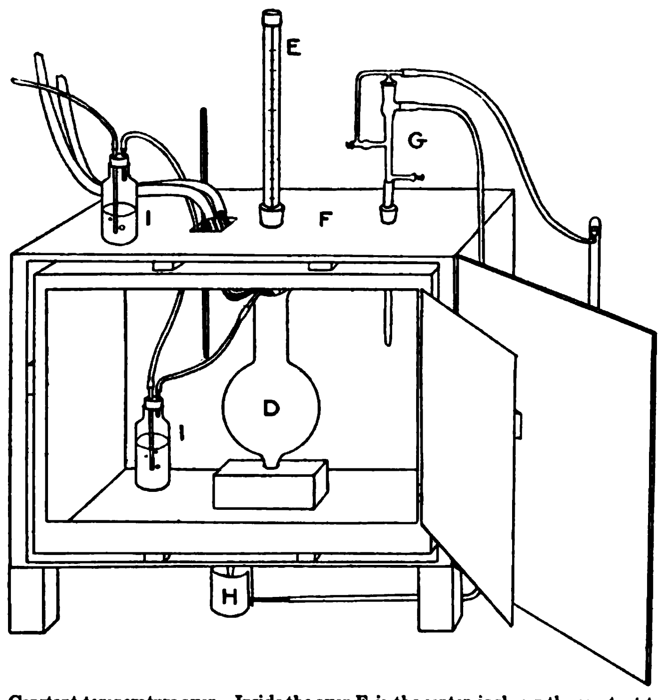


FIG. 5. Constant-temperature oven. Inside the oven F, in the center, is shown the constant-temperature flask D, with the mercury thermometer E. On the right is the thermostat G which supples gas to the burner H below the oven; at the left is the arrangement I I supplying compressed air for stirring the water in the flask D.

sufficient stratification could hardly exist to produce a sensible error in the reading. It was found, however, that appreciable temperature differences did exist in the flask and, although the thermometer bulb and thermal junctions were all at the same level, it was considered advisable to provide some method of stirring. For this reason, compressed air was introduced, being selected as a convenient method for stirring the bath, especially in view of the fact that the space available was small. By passing the air first through a vessel of water inside the oven it is brought to the temperature of the water in the flask and, still more important, is saturated with moisture at the same temperature, so that no heat is lost either by absorption or by evaporation.

To prevent cooling by evaporation from the surface, the water in the flask was at first covered by a thin film of oil; but this necessitated such an elaborate arrangement to protect the rubber tubing that the oil is now omitted, with equally satisfactory results. The performance of the constant-temperature oven has proved very satisfactory, the temperature within the flask frequently not changing more than 0.01° C. in an hour.

CALIBRATION OF MERCURY THERMOMETERS.

The following is an abstract of the calibrations of the various thermometers used in the work, as given by the Physikalisch-Technische Reichsanstalt. In the case of the Beckmann thermometers, data are given showing how the constant K, previously mentioned,[1] is determined. The tables of corrections for variations in caliber have been omitted in the Beckmann calibrations, but a statement is made regarding the maximum value of the correction.

Beckmann Thermometer PTR 40724.

Range.	Average temperature of exposed stem.	Value of scale division Jena glass 16^III.	Correction.	Corrected value of scale division.
°C.	°C.			
30-35	22	1.013	−0.008	1.005
40-45	24	1.017	−0.008	1.009

Since the thermometer is to be used at temperatures of 37° to 42° C., an interpolation has been made in the above table, giving as the corrected value of a scale division,

$$1.005+[(37-30)\div(40-30)]\ (1.009-1.005)=1.008$$

No caliber correction greater than 0.005° C. is given, so that for readings only to 0.01° C., this correction is negligible.

Beckmann Thermometer PTR 40723.

Range.	Average temperature of exposed stem.	Value of scale division Jena glass 16^III.	Correction.	Corrected value of scale division.
°C.	°C.			
30-35	22	1.013	−0.006	1.007
40-45	24	1.017	−0.006	1.011

This thermometer is to be used in calibrating at temperatures of 34° to 39° C. The corrected value of a scale division is therefore:

$$1.007+[(34-30)\div(40-30)]\ (1.011-1.007)=1.009$$

No caliber correction greater than 0.005° C. is given.

Richter Thermometer PTR 32689.

Range 34°-44° C., graduated in 0.01° C. Without sensible error throughout, *i. e.*, no correction so great as 0.005° C.

In calibrating a Beckmann thermometer in this laboratory, its zero point was determined roughly, and then the thermometer was set by trial until the

[1] Page 20.

desired value was approximately obtained. A careful determination was then made by tying the Beckmann and Richter thermometers together and immersing the pair in a Dewar flask similar to that used in the constant-temperature oven. The flask was filled with warm water stirred by compressed air, and immersed in a large body of hot water in an outside pail, the temperature of this outside water being regulated by an electric-coil heater. This heater is simply a resistance wire inclosed in a water-tight spiral tube, having in its outside electrical circuit a variable resistance, so that the amount of heating can be controlled. Several simultaneous readings of the thermometers were taken, as shown by the data given in table 1 which represent the determination of the zero point of Beckmann thermometer 40724, used in the constant-temperature oven. The Beckmann reading, corrected for caliber errors, must be multiplied by 1.008—the constant determined from the above calibration—and subtracted from the true temperature in order to give the zero point of the thermometer.

TABLE 1.—*Determination of zero point, Beckmann thermometer PTR 40724.*

Richter thermometer 32689 reading.	Beckmann thermometer 40724.		Corrected reading multiplied by 1.008.	Zero point of Beckmann thermometer.	Deviation from av.
	Reading.	Corrected reading.			
39.04	1.735	1.731	1.75	37.29	0.010
39.04	1.735	1.731	1.74	37.30	.000
39.04	1.732	1.728	1.74	37.30	.000
39.04	1.728	1.724	1.74	37.30	.000
39.04	1.726	1.722	1.74	37.30	.000
39.04	1.725	1.721	1.73	37.31	.010
39.02	1.712	1.708	1.72	37.30	.000
39.01	1.702	1.698	1.71	37.30	.000
				Av.=37.300	0.003

Thus the correct temperature as determined from a reading of this thermometer is given by the formula 37.300+1.008×reading. When working only to hundredths, the formula 37.30+1.01×reading gives closer results at the lower part of the scale, but 37.29+1.01×reading is better on higher readings.

METHOD OF OPERATING APPARATUS.

In measuring temperatures with this apparatus the procedure is first to connect the partly discharged cell to the measuring circuit for a few minutes in order to let the current become constant, and then carefully to depress the key G_1. In general, a galvanometer deflection results, indicating that the current differs from its standard value. By regulating the variables V_3 and V_4, and also, if necessary, V_1 and V_2, this deflection is brought as nearly as possible to zero, thus indicating that the current has closely enough its proper value. The current having been adjusted, the next step is to close G_2 and one of the switches 1, 2, 3, 4, etc., according to which thermal junction is to be used. In general a deflection results, which can be almost balanced by properly moving the potentiometer contacts. The attempt is not made to

balance exactly, as this requires some time, but after the balance has been obtained within perhaps 0.1° C., the potentiometer setting and the deflection are observed and noted. From time to time the current is checked as at the beginning, also the temperature of the constant-temperature bath is occasionally taken and the correction for extraneous electromotive force determined. For the purpose of making this last test the test switch T is provided. The connections are such that if this switch is closed, instead of one of the switches 1, 2, 3, 4, etc., the apparatus is in the condition usual for a temperature measurement, except that the thermal-junction system is replaced by a direct copper connection. The electromotive force in this circuit should then be zero, and if the potentiometer is set at zero, a balance should be obtained. If this is not the case, a galvanometer deflection will result, indicating the presence of an extraneous electromotive force. This error may be determined either by changing the potentiometer setting until a balance is obtained, or else—having a knowledge of the sensitiveness of the galvanometer—by interpreting it directly from the deflection. The latter method, being quicker, is perhaps preferable; it also frequently saves reversing the storage cell and standard cell, which would be necessary in balancing if the stray electromotive force happens to oppose the main voltage of the thermal-junction system.

CALIBRATION OF THERMAL JUNCTIONS.

In calibrating the thermal junctions, a Dewar flask was used, similar to that in the constant-temperature oven. This was filled with water at about body-temperature and immersed in a considerable mass of warm water in a pail, the temperature of the outside water being controlled by an electric-coil heater. The Beckmann thermometer (40723), already described, and all the junctions to be calibrated were placed side by side and bound together with rubber bands in such a way as to bring the junctions at about the middle of the bulb, but without pressure on the bulb itself. The thermometer and junctions were then inserted in the calibrating flask, the surrounding water being stirred by compressed air from the supply in the constant-temperature oven. After the temperature in the calibrating flask had become constant the Beckmann thermometer was read, the necessary potentiometer readings were made for each thermal junction, and the reading of the Beckmann thermometer in the constant-temperature oven was taken. Usually four complete series of readings were made as quickly as possible; their average furnished data which showed the relation between temperature difference and potentiometer balance for this point. After this another temperature was used in the calibrating flask and similar data obtained. In this way the junctions were calibrated throughout the range of temperature difference likely to occur in an actual experiment.[1]

[1]These conditions are also suitable for testing the constantan wire for inhomogeneity. The most important part of the circuit, namely, that where the temperature gradient is usually steepest and most variable, occurs near the junction for use on the body. This region may be explored by keeping the junction at a fixed temperature in the bath, meantime immersing the wires to varying depths. A number of tests made in this way showed no change in the galvanometer deflection, indicating that the wire was sufficiently homogeneous for this work.

Part of an actual calibration will serve to show the nature of the results obtained. After the preliminary adjustment of the current the following data were taken: First, the temperature in the flask, then as quickly as possible the potentiometer readings for the junctions A, B, C, D, E, F, and G. It might be remarked that the potentiometer setting was kept fixed throughout and the deflections noted; this saved a great deal of time. These were quickly followed by a second reading of the temperature in the flask, and also a reading of the temperature in the constant oven. Finally the stray electromotive force was measured and the current balanced as before. Then the series of observations was immediately repeated. The mercury thermometers were read to 0.002° C., and the deflections to the nearest half millimeter. The data are given in table 2.

TABLE 2.—*Calibration of thermal junctions, February* 1, 1911.

									Averages	
Initial temperature in flask..	3.774		3.770		3.775		3.745		3.761	
	Setting.	Defl.	Setting.	Defl.	Setting.	Defl.	Setting.	Defl.	Setting	Defl.
Potentiometer readings:	*ohms*	*mm.*	*ohms*	*mm.*	*ohms*	*mm.*	*ohms*	*mm.*	*ohms*	*mm.*
Junction A...	18.00	±0.0	18.00	−1.5	18.00	−4.0	18.00	−5.5	18.00	−2.7
Junction B...	18.00	+5.0	18.00	+4.0	18.00	+1.5	18.00	±0.0	18.00	+2.6
Junction C...	18.00	+7.5	18.00	+6.0	18.00	+3.5	18.00	+2.5	18.00	+4.9
Junction D...	18.00	+5.0	18.00	+4.0	18.00	+2.0	18.00	±0.0	18.00	+2.7
Junction E...	18.00	+2.5	18.00	+1.0	18.00	−0.5	18.00	−2.5	18.00	+0.1
Junction F...	18.00	+7.0	18.00	+6.0	18.00	+4.0	18.00	+2.5	18.00	+4.9
Junction G...	18.00	+7.0	18.00	+6.0	18.00	+4.0	18.00	+2.0	18.00	+4.8
Final temperature in flask.	3.774		3.770		3.775		3.740		3.760	
Temperature in oven......	2.458		2.458		2.459		2.459		2.459	
Stray deflection.........	+3.0 mm.		+2.5 mm.		+3.0 mm.		+4.0 mm.		+3.1 mm.	
Current balance[1]........	6.8 ohms		6.7 ohms		6.6 ohms		6.6 ohms		....	

[1]Not used in computations. The figure given is the reading of the variable resistance when the current is balanced.

COMPUTATIONS FOR THE CALIBRATION.

The corrected potentiometer balance differs from the setting in two respects: (1) correction for stray electromotive force must be made, and (2) since the balance consists partly of a setting and partly of a deflection, the effect of this deflection must be included.

The correction for stray electromotive force is obtained in direction and amount by consideration of the following facts: The galvanometer connections are such that a positive deflection requires a decrease in the potentiometer setting to bring it to 0; therefore, a positive stray deflection, such as is seen in table 2, by demanding a further decrease in the potentiometer setting, which is already 0, indicates a stray electromotive force opposite in direction to the net electromotive force of the thermal-junction system. Hence, the

potentiometer setting would have been greater had it not been for the presence of this extraneous electromotive force, and so the correction must be added. The actual magnitude of the stray correction is determined from the galvanometer sensitiveness and the average stray deflection. The sensitiveness of the galvanometer has been found by trial to be such that when taking the stray correction—which necessitates setting the potentiometer at 0—a deflection of 25 millimeters corresponds to a change in the potentiometer setting of 1 ohm, so that a deflection of 1 millimeter corresponds to a change in setting of 1 ÷ 25 or 0.040 ohm. The average stray deflection in the calibration just given is 3.1 millimeters. This, it is seen, is equivalent to a change in setting of 0.040×3.1 or 0.12 ohm, which is therefore the correction that must be added to the setting on account of the stray electromotive force.

When taking the readings of the thermal junctions, the potentiometer setting is no longer 0, but is increased in the present instance to 18 ohms. This change increases the resistance of the galvanometer circuit and thus reduces its sensitiveness, so that under the new conditions a deflection of 1 millimeter has been found by trial to correspond to a change in setting of 0.063 ohm. As before, a positive deflection is equivalent to a decreased balance. Thus, the final corrected balances for the different junctions are:

$$\begin{aligned}
&A,\ 18.00+0.12+2.7\times0.063=18.29\\
&B,\ 18.00+0.12-2.6\times0.063=17.96\\
&C,\ 18.00+0.12-4.9\times0.063=17.81\\
&D,\ 18.00+0.12-2.7\times0.063=17.95\\
&E,\ 18.00+0.12-0.1\times0.063=18.11\\
&F,\ 18.00+0.12-4.9\times0.063=17.81\\
&G,\ 18.00+0.12-4.8\times0.063=17.82
\end{aligned}$$

The temperature difference is determined from the average readings of the two Beckmann thermometers, one in the constant-temperature oven, the other in the calibrating flask. The temperature in the constant-temperature oven is given by the formula previously deduced:[1]

$$\begin{aligned}
\text{Temperature in oven} &= 37.300+1.008\times\text{reading}\\
&= 37.300+1.008\times2.459=39.779^\circ\text{ C.}
\end{aligned}$$

Similarly the temperature in the calibrating flask is given by the formula:

$$\begin{aligned}
\text{Temperature in flask} &= 34.365+1.009\times\text{reading}\\
&= 34.365+1.009\times3.761=38.160^\circ\text{ C.}
\end{aligned}$$

The temperature difference is then:

$$39.779-38.160=1.619^\circ\text{ C.}$$

The potentiometer balance corresponding to a certain temperature difference has now been obtained for each of the several thermal junctions, and this temperature difference accurately determined by means of the two mercury thermometers. A knowledge of the relation between these two quantities (1) potentiometer balance and (2) temperature difference, is the sole object of calibrating. This relation was determined for a number of temperature differences and the results expressed in a number of curves, one for each junction. These curves are very nearly straight lines for the range and pre-

[1] See p. 23.

cision used. Slight differences will be noted among the several junctions in the calibrations given. These are not due to experimental error, as the figures reproduce themselves very well; the cause is probably to be found in a slight inhomogeneity of the constantan wire at the different junctions. In actual experimenting the potentiometer balance is obtained, and by means of the calibration curves just described the corresponding value of the temperature difference can at once be found.

A SAMPLE BODY-TEMPERATURE EXPERIMENT.

In an experiment the junctions are placed at the different points where it is desired to obtain the temperature, being held in position when necessary by a strap or bandage. The apparatus is then operated in the manner previously described, so as to obtain data for computing the temperatures at the various points every 5 or 10 minutes, as the rate of temperature change seems to require. A few observations from an actual experiment are given in table 3, in which are noted: First, the time; next, an occasional balancing of the current; then the potentiometer readings for the various junctions, each reading consisting of a setting and a deflection as already described. After these follows an occasional reading of the Beckmann thermometer in the constant-temperature oven. Finally a column is provided for miscellaneous remarks, including observations for extraneous electromotive force, etc.

TABLE 3.—*Body-temperature experiment.*

Date: March 1, 1911. Subject: C. H. H.

Time.	Current balance.	Potentiometer readings.								Constant oven-temperature reading.	Notes.
		Junction A, Deep[1] rectum.		Junction B, Shallow[2] rectum.		Junction C, Left axilla.		Junction D, Mouth.			
		Setting.	Defl.	Setting.	Defl.	Setting.	Defl.	Setting.	Defl.		
P. M.	*ohms*	*ohms*	*mm.*	*ohms*	*mm.*	*ohms*	*mm.*	*ohms*	*mm.*		
1h11m	....	34.0	−2	34.0	−3	37.0	+1	37.0	+6	3.07	Stray
16	1.1	34.0	±0	34.0	−3	37.0	+3	36.0	+5	......	defl. =
21	....	34.0	+1	34.0	−1	37.0	+8	35.0	−4	......	+2 mm.
26	....	34.0	+3	34.0	±0	36.0	−3	35.0	−2	......	

[1]Junction about 11 cm. deep in the rectum. [2]Junction about 7.5 cm. deep in the rectum.

COMPUTATIONS FOR THE EXPERIMENT.

The method of obtaining the temperatures at the different locations and times specified involves very much the same type of computation as that used in calibrating.[1] The corrected potentiometer balance is obtained exactly as in the calibration computations by adding two quantities to the setting: First, the correction for extraneous electromotive force; and second, the deflection which has been multiplied by a factor depending on the galvanometer sensi-

[1]See p. 25.

tiveness. Having determined the corrected potentiometer balance, the temperature difference between the two junctions is found at once by reference to the calibration curves, where the relation between these two quantities is shown. The oven-temperature is computed to the nearest hundredth from the reading of the Beckmann thermometer. The body-temperature in any particular case is then found by subtracting the temperature difference from the temperature in the constant oven. The computations by means of which the various temperatures in the foregoing sample experiment were obtained are given in table 4.

TABLE 4.—*Computations for the experiment.*

Date: March 1, 1911. Subject: C. H. H.

Time.	Corrected potentiometer balance. A	Corrected potentiometer balance. B
P. M.	*ohms*	*ohms*
1^h11^m	34.0+2×.04+2×.08=34.2	34.0+2×.04+3×.08=34.3
16	34.0+2×.04+0 =34.1	34.0+2×.04+3×.08=34.3
21	34.0+2×.04−1×.08=34.0	34.0+2×.04+1×.08=34.2
26	34.0+2×.04−3×.08=33.9	34.0+2×.04+0 =34.1
	C	D
	ohms	*ohms*
1^h11^m	37.0+2×.04−1×.08=37.0	37.0+2×.04−6×.08=36.6
16	37.0+2×.04−3×.08=36.8	36.0+2×.04−5×.08=35.7
21	37.0+2×.04−8×.08=36.4	35.0+2×.04+4×.08=35.4
26	36.0+2×.04+3×.08=36.3	35.0+2×.04+2×.08=35.2

Time.	Temperature difference (from curves). A	B	C	D	Oven-temperature.	Body-temperature. A Deep rectum.	B Shallow rectum.	C Left axilla.	D Mouth.
P. M.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
1^h11^m	3.13	3.16	3.43	3.38	37.29+1.01×3.07	37.26	37.23	36.96	37.01
16	3.12	3.16	3.41	3.30	=40.39	37.27	37.23	36.98	37.09
21	3.11	3.15	3.38	3.27	....	37.28	37.24	37.01	37.12
26	3.10	3.14	3.37	3.25	....	37.29	37.25	37.02	37.14

PRECISION OF MEASUREMENT.

To meet the approximate demands of a precision discussion, the potentiometer balance may be assumed as directly proportional to the temperature difference between the hot and cold thermal junctions; hence the relation between the two can be expressed by a single factor, rather than by a curve. An approximate value of this factor, by which the potentiometer balance should be multiplied to give the temperature difference, is 0.094.

The body-temperature would then be expressed by the formula:

$$Tu = T_0 - BF$$

in which

Tu = unknown temperature
T_0 = oven-temperature
B = potentiometer balance
F = factor showing relation between potentiometer balance and temperature difference.

Assume in an average case: $T_0 = 40°$ C., $B = 32$, and $F = 0.094$. This will give for Tu a value of $40 - 0.094 \times 32 = 37°$ C.

The precision of the various factors is determined as follows: T_0 is the oven temperature as read during the course of an experiment, and has been shown in a previous paragraph to be expressed by the formula:

$$T_0 = A + KR$$

where

A = zero point of thermometer, which has been determined to at least 0.01° C.
K = 1.01 = constant
R = reading, taken to the nearest 0.01° C.

B, the potentiometer balance, is determined in the last place by deflection, which is read to the nearest half-division. The sensitiveness of the galvanometer in this case is such that a deflection of 1 division corresponds to a change in B of 0.072 ohm. Hence the average deviation in B is 0.036 ohm.

F is obtained by calibration. In calibrating, the following data are obtained: To_1, the oven temperature, which may be taken as 40° C.; Tf_1, the temperature in the calibrating flask, for instance, 37° C.; and B_1, the potentiometer balance, 32. From these the quantity $F = (To_1 - Tf_2) \div B_1$ is computed. In calibrating, the temperatures are taken more precisely than in an experiment, and this involves not only a closer reading, but a better determination of the zero point of the thermometers. As a matter of fact the reading is taken to 0.002° C.; and the zero known to 0.003° C. Therefore we may say, similarly to the above, $To_1 = A' + K'R'$ and $Tf_1 = A'' + K''R''$, where A' and A'' are known to 0.003°C.; K' and K'' are constants; and R′ and R″ are known to 0.002°C. B_1, like B, is known to 0.036.

The complete expression for the unknown temperature is then as follows:

$$Tu = A + KR - B\frac{(A' + K'R') - (A'' + K''R'')}{B_1}$$

The average deviations of the variables are:

A, $a.d. = 0.01$; R, $a.d. = 0.01$; B, $a.d. = 0.036$; A', $a.d. = 0.003$; R', $a.d. = 0.002$; A'', $a.d. = 0.003$; R'', $a.d. = 0.002$; B_1, $a.d. = 0.036$.

The constants K, K', and K'' each have the value 1.01.

The effect on the final result of the deviation in each component is obtained by the aid of the differential calculus. Adopting the usual notation:

$$\Delta A \ = 0.01 \qquad \Delta R = K \times 0.01 = 0.01$$

$$\Delta B \ = \frac{(A'+K'R') - (A''+K''R'')}{B_1} \times 0.036 = \frac{3}{32} \times 0.036 = 0.0034$$

$$\Delta A' = \frac{B}{B_1} \times 0.003 = 0.003 \qquad \Delta R' = \frac{BK'}{B_1} \times 0.002 = 0.002$$

$$\Delta A'' = \frac{B}{B_1} \times 0.003 = 0.003 \qquad \Delta R'' = \frac{BK''}{B_1} \times 0.002 = 0.002$$

$$\Delta B_1 = \frac{B[(A'+K'R') - (A''+K''R'')]}{(B_1)^2} \times 0.036 = \frac{3}{32} \times 0.036 = 0.0034$$

The deviation in the final result will then be

$$\Delta = \sqrt{(.01)^2 + (.01)^2 + (.0034)^2 + (.003)^2 + (.002)^2 + (.003)^2 + (.002)^2 + (.0034)^2}$$
$$= 0.016^\circ \text{ C.}$$

It is thus seen that the deviation expected in the body-temperature, caused by the deviations in the various components, is 0.016° C.; that is, each temperature is measured to 0.01° or 0.02° C. It should be remembered, moreover, that the primary object of this study is to determine the temperature differences between different points of the body rather than the absolute temperatures. A number of circumstances can be conceived which might cause an error in the absolute determination of temperature, but which would be without effect on the difference between two temperatures. The results stated therefore are regarded as singularly good.

LATER MODIFICATION OF THE APPARATUS.

After the conclusion of this research, it was desired to extend the application of the apparatus to the determination of the rectal temperatures of subjects in the respiration calorimeters installed in this laboratory. It was thought undesirable, however, to reserve the Wolff potentiometer for this special work, as to do so would preclude its being used for any other measurements; therefore a special potentiometer for body-temperature measurements has been constructed. The circuit arrangement of this instrument is somewhat different from the ordinary potentiometer, and was suggested informally to one of the writers by Dr. Walter P. White, of the Geophysical Laboratory of the Carnegie Institution of Washington in Washington, D. C. It is a pleasure here to acknowledge our indebtedness to Dr. White, whose unusual experience with thermal junctions made his suggestions doubly valuable.

The new arrangement completely removes all sliding contacts from the galvanometer circuit and thus frees this important circuit from the thermal electromotive forces which are developed by the usual type of sliding contact. An elementary diagram of the apparatus is shown in fig. 6. The battery B

sends a current through the circuit B–P–D–R–A–B, this current being measured by the ammeter A. The contact P may be moved until the fall in potential along P–D, due to the battery current, is just equal to the voltage of the thermal-junction system TT. When this condition is fulfilled—as indicated by the absence of a galvanometer deflection—the voltage of the thermal-junction system may be computed directly from the constants of the apparatus. As before, however, the temperature difference between the junctions rather than their voltage is desired; and this may be obtained in the usual way by calibration.

The complete wiring diagram is shown in fig. 7. It will be noticed that, as in the older type of apparatus, the ammeter A is replaced by a standard cell N and galvanometer; also a variable resistance V is included in the main circuit for adjusting the current always to approximately the same value;[1] and the galvanometer is provided with a number of switches by means of which it may be connected to any one of a series of thermal-junction pairs, or to the standard cell circuit. The circuit has a great many features in common with that of the earlier apparatus previously described in detail,[2] and these need not be considered again at this point. Some differences, however, will be noted. The galvanometer sensitiveness is independent of the position of the contact P, since moving this contact in no way affects the resistance of the galvanometer circuit. The sensitiveness being constant, a resistance W has been inserted in the galvanometer circuit, and by this means the sensitiveness adjusted until the deflection reads directly in hundredths of a degree. No special provision is made for reversing B and N, as experience with the earlier apparatus showed this to be unnecessary. The new apparatus differs from the old, also, in that the thermometer must be detachable. Two heavy wires have therefore been run to two metal blocks in each calorimeter, and to these the thermometer can easily be attached. It will be noted in fig. 7 that each calorimeter is not provided with an entirely independent set of connections, but that the chair calorimeter and calorimeter No. 4 are connected in parallel, as are also calorimeters Nos. 3 and 5. This is allowable because other considerations prevent the calorimeters thus joined from ever being used at the same time.

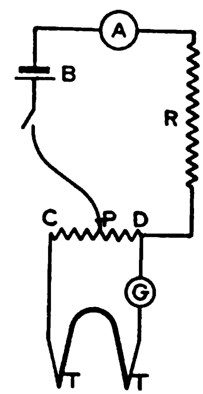


FIG. 6. Elementary wiring diagram of modified apparatus. Current from the battery B flows through PD, this being part of the slide wire CD, then through the resistance R and finally returns to the battery through the ammeter A. The thermal junction system TT is connected through the galvanometer G to the points C and D, this circuit being free from sliding contact.

[1]It will be seen that the method as described is approximate only, and not exact, since the measuring current changes with each position of P. The error thus introduced may be made negligibly small for any case by making R sufficiently large as compared with CD. The resistance CD should be kept small from another standpoint as well, namely, that of sensitiveness. By the use of some kind of compensating resistance, equal to CD and arranged so as to be decreased as CD is increased, and *vice-versa*, the arrangement can be made exact.

[2]See pp. 14–22.

The apparatus is designed to measure temperatures to 0.02° C., and has a range of 8° C. The voltage of the cell B is 1.4 volts; that of N, 1.0197 volts.

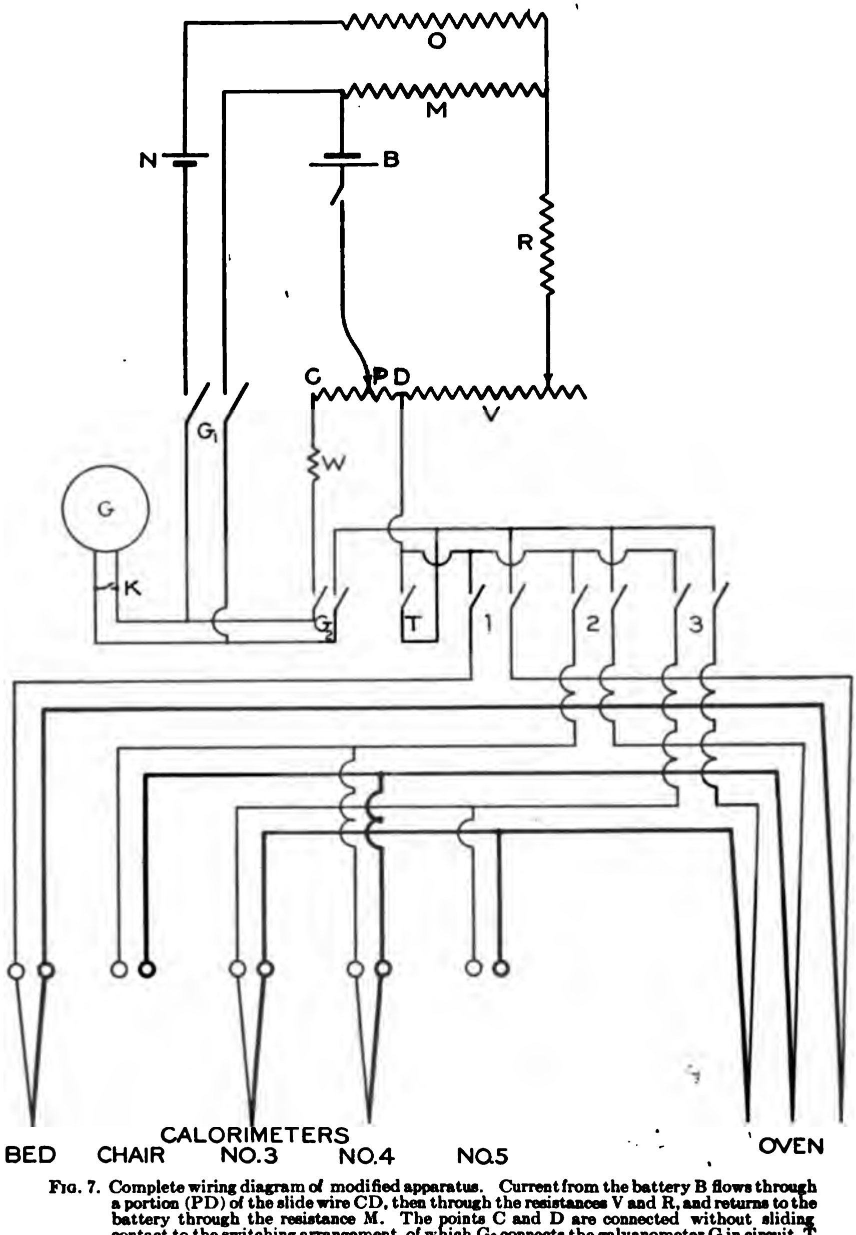


FIG. 7. Complete wiring diagram of modified apparatus. Current from the battery B flows through a portion (PD) of the slide wire CD, then through the resistances V and R, and returns to the battery through the resistance M. The points C and D are connected without sliding contact to the switching arrangement, of which G_2 connects the galvanometer G in circuit, T replaces the thermal junction system when testing, and 1, 2, and 3 are connected to the thermal junctions in the calorimeters and the constant-temperature oven. The constantan wires are indicated by the heavy lines; the calorimeter thermometers are detachable at the small circles. W is a resistance for adjusting the galvanometer sensitiveness. N is the standard cell, protected by the high resistance O, and connected to the circuit through the double contact key G_1. The switch K is for convenience in bringing the galvanometer to rest.

Copper-constantan couples are used, as previously. The slide wire C–D has a resistance of 0.372 ohm, and is divided into 400 divisions, each of which represents 0.02° C. temperature difference; M has a value of about 1200 ohms; and R, about 400 ohms. The maximum resistance of V is about 100 ohms; this should be variable in steps of about 1 ohm each. The value of W has not been measured, this resistance having been adjusted by trial. O, as before, is 10,000 ohms. For B a dry cell is used, from which a measuring current of about 0.00086 ampere is drawn; N is the Weston Standard cell used

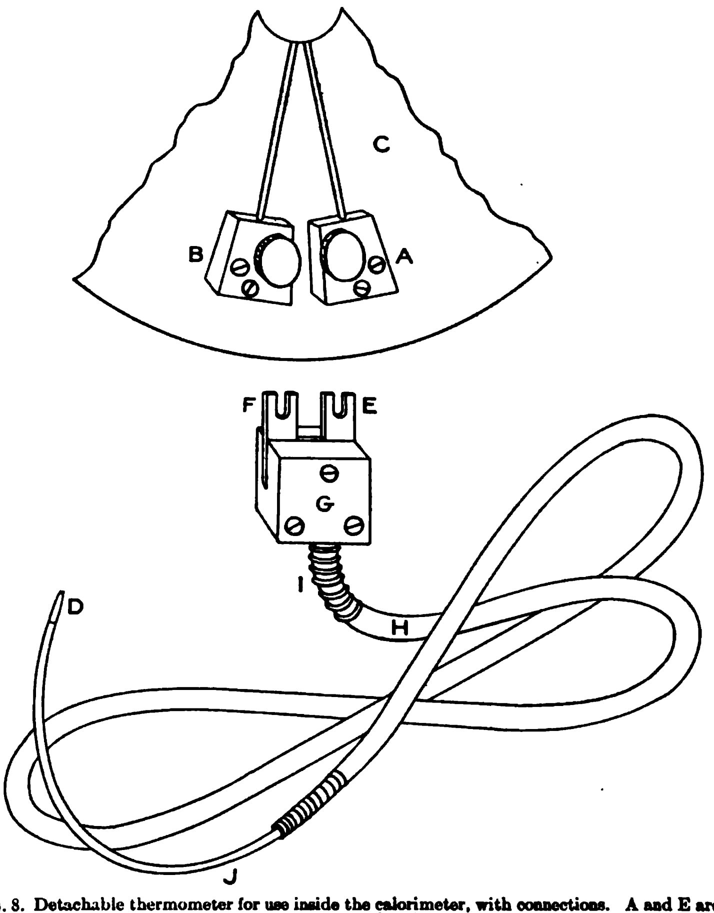


FIG. 8. Detachable thermometer for use inside the calorimeter, with connections. A and E are of constantan; B and F of copper.

previously. The potentiometer C–D consists of a 0.6 millimeter manganin wire, arranged in the form of a circle, the sliding contact P being operated by a knob at the center. The resistances M, R, V, and O are of manganin.

The constantan wire from the constant-temperature flask to the inside of the calorimeter is 2.05 millimeters in diameter, insulated with rubber and covered with a protecting braid. As will be seen in fig. 8, this wire is soldered

at the calorimeter to a small constantan block A, and in the same way the copper wire running to the calorimeter is soldered to a small copper block B. These blocks are mounted on a hard-rubber base C, and are provided with binding screws of constantan and copper, respectively, by means of which the thermal junction may be connected to the circuit without the intervention of any metal other than the two required for the thermometer itself.

The thermometer consists of two wires 1.6 meters long, 0.0455 millimeters in diameter, of constantan and copper respectively, well insulated, and soldered together at one end D. At the other end the wires are screwed to two flat terminals of constantan E and copper F, which are shaped to be received by the binding screws already mentioned. These flat terminals are mounted on a hard-rubber block G to which the wires are fastened in such a way as to make the joint absolutely rigid. The wires are covered by a 6.4 millimeter rubber tube H down to some 25 centimeters from the junction itself; this tube is protected by a spiral spring I at the point where it leaves the hard-rubber block G. This comparatively heavy tubing is continued by a smaller thin-walled rubber tube J for the remainder of the distance to the thermal junction; this thin tubing fits tightly around the wires and is closed at the end D by being tied tightly with silk.

It should be remarked that considerable trouble has been experienced by extraneous electromotive forces developed at the point where the constantan wire from the thermal junction is soldered to the flat constantan terminal E. This stray electromotive force has been found to be reduced practically to zero when the soldered connection is replaced by a clamp connection, made by fastening the wire under the head of a small constantan screw, without the use of solder. Apparently in this case the electromotive force is due not to difference in the constitution of the two pieces of metal, but rather to the unbalanced effect of the constantan-solder and solder-constantan couples. This leads to the conclusion that when it is necesary to solder two pieces of metal of identical constitution together, stray electromotive forces will be less likely to be developed if the two pieces have the same size and shape and are surrounded by as nearly as possible the same conditions of heat loss.

The operation of the apparatus is identical in procedure with the earlier form. The current is first balanced, after which the potentiometer balance is found, partly by setting, partly by deflection. Occasional observations are also required of the temperature in the oven and the stray electromotive force.

PART III.—DISCUSSION OF RESULTS.

While this investigation was primarily undertaken to study simultaneously the temperature in different parts of the body, many secondary points of considerable importance were naturally encountered in the process of the investigation.

THERMAL GRADIENT OF THE BODY.

The method of electrical measurement here outlined, owing to its extreme sensitiveness and delicacy, is admirably adapted for a study of the thermal gradient of the body. As has been previously shown, with an internal body-temperature of not far from 37° C. and a surface temperature of about 32° C. one would expect normally a thermal gradient. The exact significance of this gradient may be better understood after a consideration of certain points with regard to the physical structure of the body. If the highest heat production were at the exact center of the body and there was a definite thermal gradient from the center to the skin, it is obvious that the measurement of body-temperature, particularly the average body-temperature, would present almost insuperable difficulties. One could not select a point half-way between the surface of the skin and the center of the body and assume that the temperature at this point would represent the average body-temperature, since there would be no way of obtaining a record of this temperature. On the other hand, if the thermal gradient rose sharply for the first few centimeters beneath the surface of the skin and soon reached a point beyond which the body temperature was not materially increased, the problem would be much less complicated. If, as is frequently the case, we desire to note the total amount of heat actually latent in the body at a given time, we must know the body-temperature as nearly as possible. Consequently a study of the thermal gradient was first made.

METHOD OF STUDYING THE THERMAL GRADIENT.

In studying the thermal gradient, the rectum was used with men, and the rectum and the vagina with women, both being deep cavities into which the thermal junctions could be inserted for a considerable distance. It is obvious that at the entrance of either of these cavities the temperature will be low, *i. e.*, that of the environment, but as the thermal junction is inserted deeper into the cavity, the temperature more nearly approximates that of the interior portion of the body. The important point to note, then, is the depth of insertion required to obtain the maximum temperature. For this purpose, two thermal junctions were inclosed in a single tube, and bound together in such a way that one was exactly 3.5 centimeters from the other. This tube was then inserted in the cavity to be studied, so that the deeper junction was approximately 10 centimeters within the cavity and the other accordingly 6.5 centimeters. Readings were taken until constancy had been obtained; then both thermometers were withdrawn to a new location in the cavity, and the measurement repeated. By this means the whole region was studied, the two ther-

mometers allowing simultaneous observations, each serving as a check upon the other. With women, observations could be made simultaneously in the rectum and the vagina.

EXPERIMENTAL RESULTS.

The results are expressed in the form of curves (see figs. 9, 10, 11, 12, and 13), in which the depths of insertion are expressed by horizontal distances, the corresponding temperatures being represented vertically. The records for rectal observations are marked R_D and R_s for the deep and shallow temperatures respectively; in a similar manner the curves for the deep and shallow vagina are designated by V_D and V_s. In some instances, when only a single thermometer was used in either cavity, the subscript is naturally omitted.

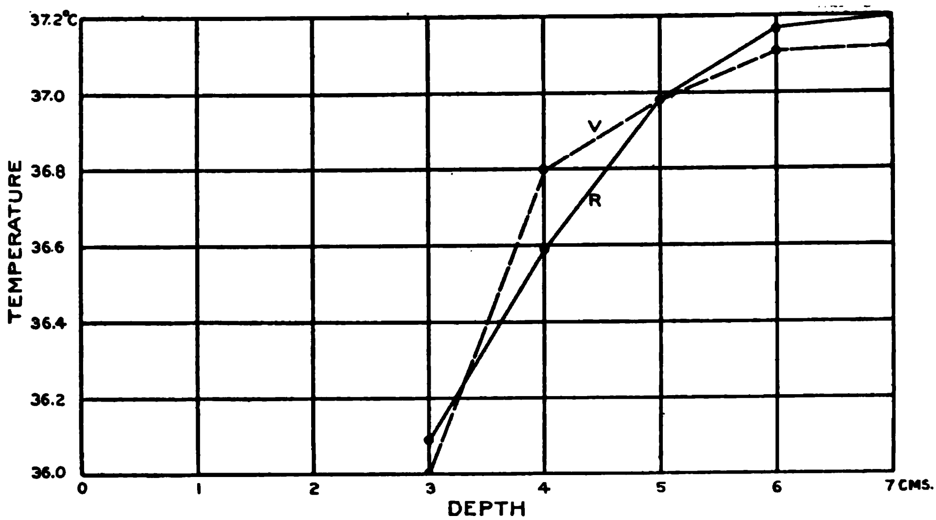


FIG. 9. Observations on thermal gradient, with Mrs. B—1.

In the experiment represented by fig. 9, observations were made on a woman (Mrs. B—1) with one thermometer in the rectum and a second in the vagina, the double thermometer not being used in either case. The actual temperature observations are given in table 5.

TABLE 5.—*Thermal gradient observations.*

Rectal thermometer.		Vaginal thermometer.	
Insertion.	Temperature.	Insertion.	Temperature.
cm.	*°C.*	*cm.*	*°C.*
7	37.20	7	37.12
6	37.17	6	37.11
5	36.98	5	36,98
4	36.59	4	36.80
3	36.09	3	36.00

The results show that at a depth of 3 centimeters in either cavity the temperature was over a degree lower than at a depth of 7 centimeters. The rise was rather regular and gradual up to 5 centimeters; beyond that point the rise was much slower and between 6 and 7 centimeters it nearly ceased, indicating that in this case and under the conditions of the experiment, the maximum body-temperature was reached when the thermometer was inserted 6 or 7 centimeters in the vagina or the rectum.

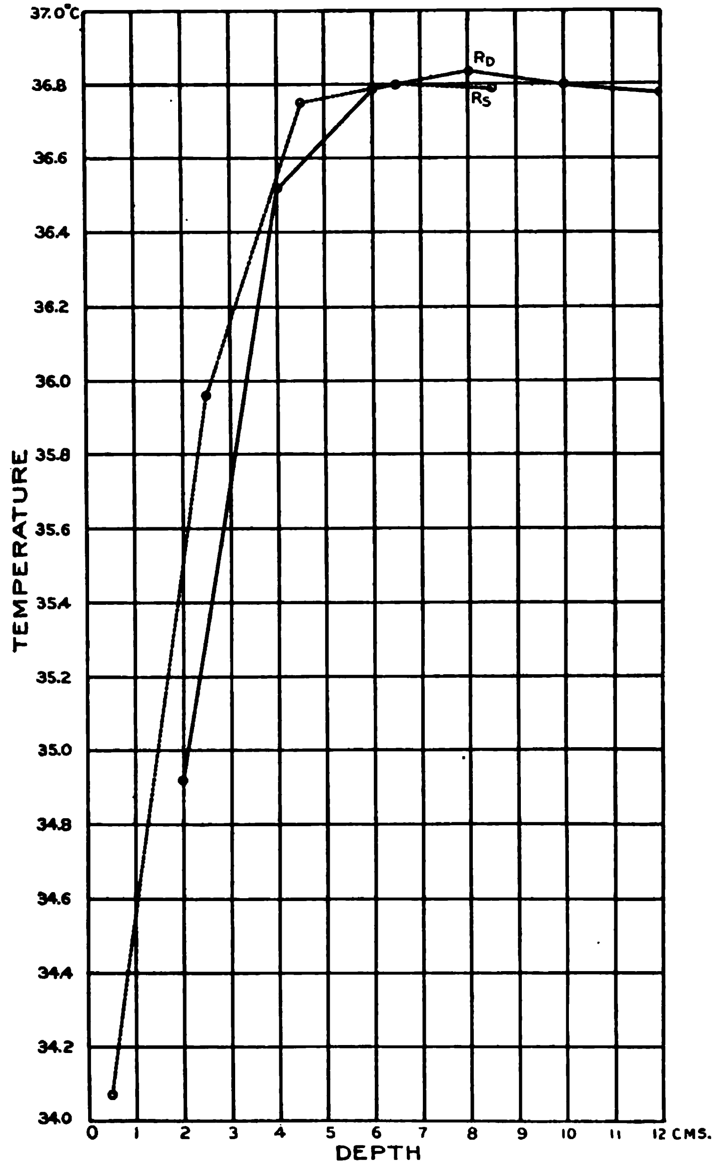


FIG. 10. Observations on thermal gradient, with C. H. H.

In the experiment represented by fig. 10, a double thermometer was used in the rectum, one of the laboratory assistants (C. H. H.) serving as a subject. It is interesting to note from the curves that between the depths of 0.5 centimeters and 6 centimeters, there is a difference in temperature amounting to 2.72° C. The curves rise very rapidly until the depth of 4 centimeters is reached, continuing to rise much more slowly for the next 2 centimeters. Apparently with this subject the temperature reached its highest point at a

depth of about 6 centimeters, and from 6 to 12 centimeters there was no material variation.

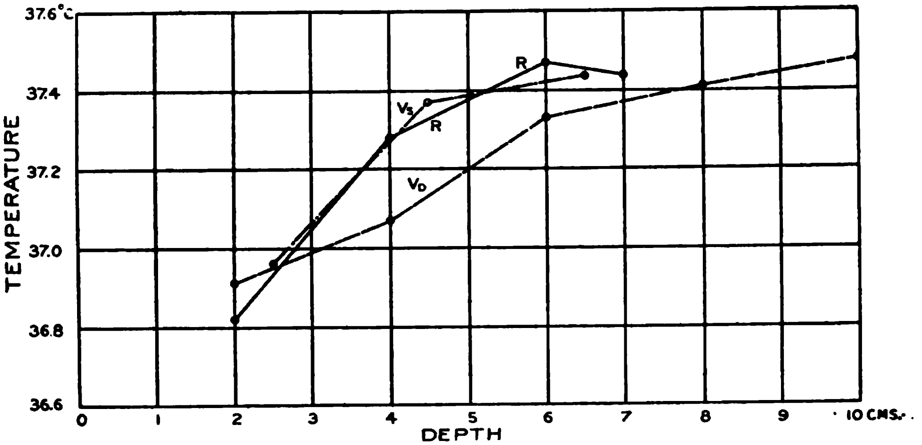


FIG. 11. Observations on thermal gradient, with Mrs. B—l.

The experimental results shown in fig. 11 were obtained with the woman subject previously mentioned, a double thermometer being used in the vagina and a single thermometer in the rectum. The curves show in a general way the characteristics of the curves in the preceding tests, although the gradient is not so sharply indicated.

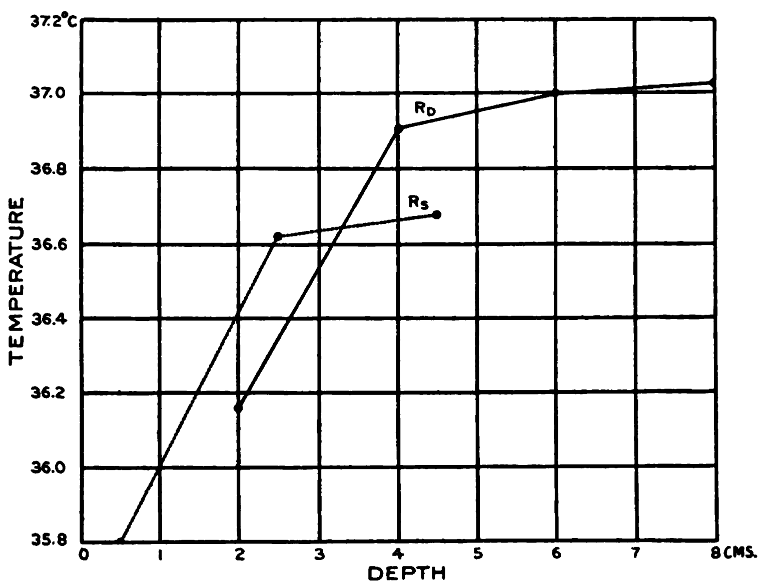


FIG. 12. Observations on thermal gradient, with J. J. C.

A thermal-gradient experiment was made with another laboratory assistant (J. J. C.) in which a double thermometer was used in the rectum, the results being shown in fig. 12. With this subject the temperature at a depth of 0.5

centimeters was 35.80° C., and at 8 centimeters 37.03° C. No material differences were noted between 6 and 8 centimeters. As usual the gradient rose very sharply up to a depth of 6 centimeters, after which the temperature remained practically constant.

The records for a third experiment with the woman subject are given in fig. 13; in this experiment a single thermometer was used in the vagina and a double thermometer in the rectum. The temperature rose very rapidly until about 5 centimeters was reached; afterwards it remained essentially constant for the remaining distance between 5 and 10 centimeters, beyond which point it was not studied. The temperature at 2 centimeters was about 36.8° C. and at 10 centimeters 37.3° C., showing a difference of approximately 0.5° C.

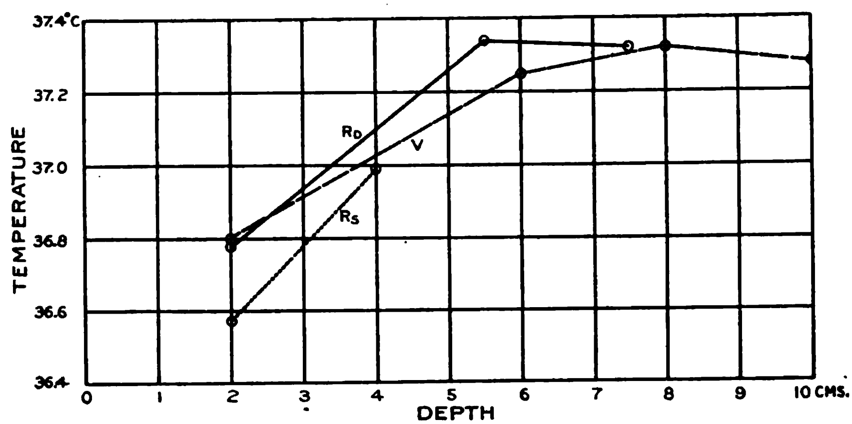


FIG. 13. Observations on thermal gradient, with Mrs. B—l.

GENERAL CONCLUSIONS WITH REGARD TO THE THERMAL GRADIENT.

It is apparent, therefore, that the thermal gradient between the temperature at the surface of the body and at a depth of about 5 centimeters is quite noticeable; evidently beyond 5 centimeters the body-temperature is essentially at its maximum. It has been neither disproved nor shown by this study, of course, that the temperature may not be actually higher in the liver or in some other active organs of the body; indeed, it is to be expected that where there is special metabolic activity, as in the liver and other glands, there might be a somewhat higher temperature. On the other hand, Rancken and Tigerstedt,[1] who found that ordinarily the temperature in the stomach was about 0.1° C. higher than that in the rectum, were unable to note any rise in temperature during the first hour of active digestion, except such as was due to the heat of the food. However, in finding the average temperature of the human body, it appears safe to say that the temperature rises to its highest point at a depth of 6 to 7 centimeters.

[1]Rancken and Tigerstedt, Biochem. Zeitsch., 1908, 11, p. 36.

From the very sharp gradient, it may be easily inferred that the surface temperatures of the body, or those slightly below the surface, are liable to the greatest errors in determination, and consequently, as ordinarily measured, they can have but little physiological significance.

SELECTION OF LOCALITIES FOR SIMULTANEOUS MEASUREMENT OF FLUCTUATIONS IN BODY-TEMPERATURE.

NATURAL CAVITIES.

The rectum and the vagina used alone are not especially suitable for studying the constancy or the lack of constancy of temperature fluctuations in different parts of the body, since these two cavities are side by side. Unfortunately no other cavity presents such ideal conditions for the study of fluctuations in body-temperature as do these, the only other openings which could be used being the mouth and the œsophagus. While it has long been the custom of physicians and physiologists to take temperatures in the mouth, certain grave objections have been raised to the use of this locality, and it is obvious that a more careful study of buccal temperature should be made before relying upon this cavity for exact temperature measurements. Accordingly, a considerable amount of experimenting was done in connection with this research to test the reliability of temperatures taken in the mouth.

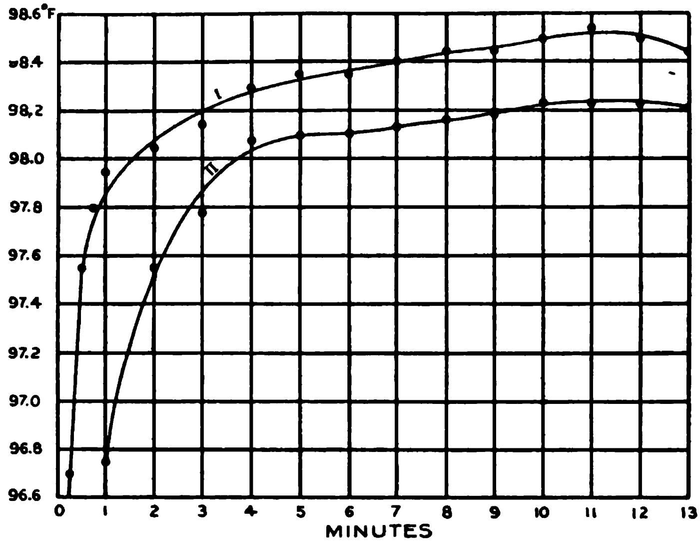
TEMPERATURE MEASUREMENTS IN THE MOUTH.

A variety of methods were used for taking mouth temperatures, but even when extreme care was observed, the results were unsatisfactory. The experiment was tried, for instance, of inserting a thermal junction beneath the tongue and recording the temperature until it became constant; the thermal junction was then withdrawn and immediately replaced by a carefully calibrated clinical thermometer[1] which was allowed to remain in position for 5 minutes. The temperatures indicated by the two measurements were not identical, the thermal junction giving results 0.2° to 0.4° F. lower. Again, the mercurial thermometer and the thermal junction were fastened together and inserted beneath the tongue for a period of possibly 20 minutes, the thermal junction being read at regular intervals until a maximum was reached, this requiring some 15 minutes. When the maximal reading was compared with the clinical thermometer reading it was found to be 0.1° to 0.3° F. lower than the latter.

This continual disagreement led to a doubt as to the wisdom of using this locality for taking temperature records, and of the clinical thermometer as a standard. As a further test, the experiment was then tried of tying two clinical thermometers together, inserting them in the mouth, and removing them at the end of 5 minutes to take the records. After the thermometers had been shaken down, they were replaced in the mouth and further 5-minute

[1]Inasmuch as the Fahrenheit degree is employed in graduating practically all of the mercurial clinical thermometers used in this country, this unit is made the basis of the discussion of buccal temperatures, although in all other sections of the report the centigrade scale is regularly used.

records taken. For approximately 10 minutes the readings of the two thermometers disagreed; afterwards they were identical. This led to the belief that unequal conditions of heat loss caused the discrepancies observed in the earlier readings. To equalize this heat loss, warm water was held in the mouth and simultaneous records taken with the thermal junction and the clinical thermometer, the water acting in a way as a protection from outside temperature influences. The results showed the thermal junction in one instance to have the same maximal temperature as the clinical thermometer, but usually it was 0.2° to 0.3° F. lower. Then the thermal junction was embedded in paraffin, and its records compared with those of the clinical thermometer. The results showed that even under these conditions the thermal junction readings ranged from 0.1° higher to 0.3° F. lower than those of the clinical thermometer.



F. 14. Observations showing the rise of temperature in the mouth. (I) clinical thermometer, (II) thermal-junction thermometer.

Finally the design of the thermal junction was changed. In all of the previous experimenting with the mouth temperature, a junction of either type A or C (fig. 3) was used.[1] The new junction was built with a heavy, pear-shaped, copper element, the bulb of which was about 1 centimeter in diameter. The constantan element, a small wire, was soldered to the copper at about the center of the bulb, by means of a small hole drilled through to this point. This junction was then compared with the clinical thermometer, as in the previous experiments. The results obtained from six comparisons show that the thermal junction and clinical thermometer agreed in three cases, the thermal junction was 0.1° F. higher than the clinical thermometer in two cases, and 0.2° F. higher in the remaining case.

[1]See p. 18.

Two curves are reproduced in fig. 14, showing records obtained in the mouth with a clinical thermometer and with a thermal-junction thermometer. In these curves the intervals of time during which the thermometer was held in the mouth are expressed by horizontal distances, the corresponding temperatures being represented vertically.

Curve I may be of interest in showing that a clinical thermometer inserted beneath the tongue does not attain its maximal temperature for a considerable time. The curve was obtained in the following way: A subject carefully trained to the use of a clinical thermometer, after preparing for the experiment by keeping his mouth closed for perhaps 10 minutes, seated himself and placed a clinical thermometer beneath the tongue, allowing it to remain for 15 seconds. He then removed the thermometer, read it, quietly shook it down, and replaced it, this time for 30 seconds. This procedure was repeated, the thermometer being kept in place during constantly increasing periods of time up to 13 minutes. Even after the thermometer had been inserted 7 minutes, a further rise of over 0.1° F. was noted; this, it would seem, must have been caused by the slowness of the cavity in warming up, as the true body-temperature must have been slowly falling on account of the quietness of the subject.

Curve II was obtained shortly afterwards with the thermal junction; in this case, however, the procedure was greatly simplified. The thermometer was inserted at a definite instant and its temperature taken each minute by means of the usual measuring apparatus. The curve is similar in shape to that obtained with the clinical thermometer; the maximal temperature indicated is, however, somewhat lower.

Having obtained such inconstant results in the mouth with these two types of thermometers, an attempt was made to find out if better comparisons could not be obtained in the rectum. The experiment was accordingly tried of inserting the thermal junction about 7 centimeters into the rectum, taking readings for perhaps 15 minutes until constancy was assured, then removing the thermometer and replacing it by a clinical thermometer inserted to the same depth. The results given by the thermal junction varied from 0.1° F. lower to 0.2° F. higher than the clinical thermometer.

When the thermal junction and the clinical thermometer were fastened together in a single rubber tube and inserted in the rectum, the maximal reading of the thermal junction in one case was identical with that of the clinical thermometer, while in another instance it was 0.2° F. lower than the clinical thermometer. This pointed to an error in the thermal-junction reading, but a further test was made which showed that the reading of the clinical thermometer was by no means an indisputable standard. In this test, two carefully calibrated clinical thermometers were inserted in a rubber tube and placed in the rectum. After 10 minutes they were withdrawn, carefully removed from the tube, and read. The readings were not identical, but disagreed by 0.1° to 0.2° F.

In order to make sure that the presence of the rubber tubing did not vitiate the results, a thermal junction and a clinical thermometer were inclosed in

rubber tubing exactly as for an experiment. They were then immersed in a bath of warm water and readings were taken continuously of the thermal junction temperature; at the end of 10 minutes, they were withdrawn from the water, the tubing removed, and the clinical thermometer read. In one test, at a temperature of 98° F., the reading of the clinical thermometer agreed exactly with the record obtained with the thermal junction; in a second test, at a temperature of about 99.4° F., the records disagreed by 0.4° F. Shortly afterwards the clinical thermometer used was broken, so that this result could not be verified.

Although no definite conclusion was reached, these comparison experiments left in the minds of the experimenters grave doubts as to the feasibility of using the mouth in temperature observations, and also an indefinite distrust of the clinical thermometer for accurate work. It should be stated that a type of mercurial thermometer was used that probably represented as good an instrument as is ordinarily available, selection being made from a number of thermometers that had been simultaneously calibrated. It is evident that the rise of mercury in the thread in a series of impulses may easily lead to errors as great as 0.2° F., and hence whatever value the mercury self-registering thermometer has to the clinician, it can have little, if any, value when accurate body-temperature measurements are desired.

ARTIFICIAL CAVITIES.

In the effort to find favorable places for making temperature observations, certain artificial cavities, such as the closed axilla or groin, or between the closed hands, were carefully studied. These so-called cavities are really more or less exposed portions of the skin, the configuration of which has been changed so as to form a closed pocket. On account of the large amount of subcutaneous fat, greater possibilities for finding such cavities are afforded with women than with men; accordingly, in experiments with a woman attempts were made to study the temperature fluctuations by means of a thermometer placed between the arm and the breast, between the two breasts, and in different parts of the body more or less inclosed by flesh.

The one great difficulty with all of these so-called artificial cavities is that they require considerable time to warm them to the maximum temperature. The temperature of the exposed skin before the cavity is made may be as low as 32° C., while that in the inclosed cavity, equilibrium having once been established, may be 36° or 37° C. At the beginning of a test, therefore, the cavity will have a temperature not far from 32° C., and will gradually become warmed to 36° C. or thereabouts, before it can be used for comparison with natural cavities, such as the rectum and the vagina. The warming-up period usually occupies 20 or 30 minutes for the axilla, the length of the period depending principally on the closure obtained. For the cavities made by the groin and by the hands, the preliminary warming period is even longer, since these cavities are formed from places ordinarily less inclosed than the axilla. To avoid this loss of time, a hot-water bottle, previously filled with water at

a temperature 2° or 3° C. higher than that of the body, was placed in the inclosed portion for 5 minutes before inserting the thermometer. By this means the cavity was preheated to approximately normal temperature, and came to its final value in about half of the time previously required.

SIMULTANEOUS OBSERVATIONS OF BODY-TEMPERATURE IN DIFFERENT LOCALITIES.

From the previous discussion of the thermal gradient it is obvious that it would be practically impossible to determine the average temperature of the human body, although as a gradient effect is most marked in the last peripheral 4 centimeters of body material, a large portion of the body would have a temperature not far from that of the rectum. Fortunately, for purposes of calorimetry, what is chiefly desired is the fluctuations in temperature from hour to hour or from day to day. One must be sure that the fluctuations in temperature throughout the whole body are of equal value, since otherwise no accurate estimate can be made of the total heat gained or lost due to a rise or fall in temperature.

The temperature of the body rarely remains constant, even for so short a time as 10 minutes; this was shown by a series of observations[1] made every 4 minutes for several days in which practically no two consecutive readings were exactly alike. The normal temperature rhythm, with a maximum between 4 and 5 o'clock in the afternoon and a minimum between 2 and 5 o'clock in the morning, is considerably accentuated by a number of extraneous factors, but even with the subject lying in bed without food, or with a small amount of food, the range in temperature in 24 hours may be as high with a normal subject as 1.3° C. (2.3° F.).

In the collected results of body-temperature measurements obtained in a large number of experiments with the respiration calorimeter at Wesleyan University, Benedict and Carpenter[2] report that the average body-temperature in experiments with food was 36.82° C. (98.3° F.), the minimum being 35.67° C., and the maximum, 38.23° C. The average range for all of the experiments was 0.96° C., the minimum range, 0.44° C., and the maximum, 1.64° C. In a series of experiments with 11 subjects in which food was not taken, covering in all 31 days of 24 hours each, the average temperature of the subjects was 36.67° C. (98° F.). The minimum temperature observed was 35.53° C., and the maximum, 37.74° C. The average range in temperature was 0.77° C., the minimum range being 0.38° C., and the maximum, 1.36° C. (2.45° F.).

The large number of observations made on body-temperature by electrical methods in the last few years have shown that there are fluctuations aside from the normal rhythm—fluctuations that can be produced artificially; for example, changing from a lying to a sitting position will cause a slight rise in temperature, as will also the taking of hot drinks or hot food. Eating a meal may cause a rise of as much as 0.15° C. in 20 minutes, and severe muscular

[1]Benedict and Snell, Archiv f. d. ges. Physiol., 1902, 90, p. 33.

[2]Benedict and Carpenter, Publication No. 126, Carnegie Institution of Washington, 1910, p. 121.

work as much as 0.50° C. in 30 minutes. In fact, any increase in body activity tends to increase the temperature. On the other hand, muscular relaxation and sleep, as well as cold water and cold food, will cause a fall in temperature. Consequently, in certain of our experiments the effort was made by various means to produce artificially these fluctuations in temperature in order to enable us to secure better conditions for measurements of temperature fluctuations in different parts of the body.

The 24 experiments in this study of body-temperature were all made with healthy people, including five men and one woman; the data regarding the age, height, and weight of these subjects may be found in table 6. With but few interruptions, the experiments continued daily from the beginning of January until the middle of March, 1911. The experimental conditions remained essentially the same throughout the series, save that in all experiments prior to January 27, 1911, the water in the Dewar flask inside of the constant-temperature oven was not stirred by compressed air. While this change in the apparatus tended to insure a constancy of temperature that added somewhat to the accuracy of the subsequent results, nevertheless the experiments were usually of short duration, and hence were not subject to wide errors due to imperfect stirring.

TABLE 6.—*Age, height, and weight of subjects.*

Subject.	Age.	Height.	Weight without clothing.
	years.	*cm.*	*kilo.*
Mrs. B—l..	43	164	56
F. G. B....	40	183	83
J. J. C....	27	175	65
C. H. H....	18	169	55
V. G......	17	162	55
F. A. R....	34	163	74

Previous to an experiment, the thermometers were adjusted and the subject immediately lay down on a comfortable couch or occasionally sat in a chair, changing the position from time to time to avoid extreme discomfort. In each experiment one main question was usually studied, and incidentally numerous minor points. In giving the results, therefore, it seems best to present the curves for each experiment by itself, with the conclusions drawn therefrom, and finally to summarize the results and give the conclusions drawn from the experiments as a whole. In these curves, as usual, the time is expressed by distance measured horizontally and temperature is represented vertically. The records for the various localities are designated as follows: Deep rectum, R_D; shallow rectum, R_S; deep vagina, V_D; shallow vagina, V_S; right axilla, A_R; left axilla, A_L; mouth, M; groin, G; upper leg, L; hand, H_c and H_r; and various surface points, S.

EXPERIMENTAL RESULTS.

Experiment of January 6, 1911, *with C. H. H.*—A thermometer was placed in each axilla, and two thermometers in the rectum, one of the latter being inserted 10.4 centimeters, and the other 6 centimeters. The experiment began shortly after the subject reached the laboratory in the morning, and it will be noticed that in consequence there was an initial fall in temperature of both the rectal thermometers. This is usual after muscular exercise, even so

limited an amount of exercise as would be incidental to coming to the laboratory. The length of time required to raise the temperature in the axilla to constancy was from 20 to 30 minutes; when constancy had been assured, the axillas were opened and cooled for a short time, and the thermometers again inserted.

The two axillas had about the same temperature curve, and in a general way the fluctuations followed those in the rectum; the records of the axilla thermometers were, however, lower than those of either the shallow or the deep rectal thermometer.

The results of the measurements are shown in fig. 15, in which the curves are marked as previously indicated.

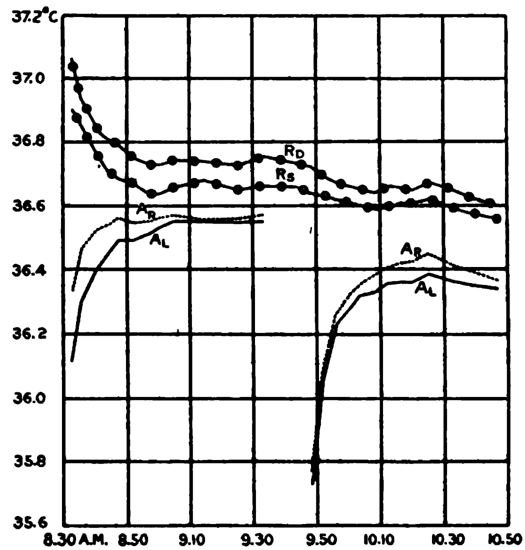


FIG. 15. Temperature curves for experiment of January 6, 1911, with C. H. H.

Experiment of January 6, 1911, *with Mrs. B—l.*—This experiment was made primarily to test the feasibility of obtaining the body-temperature of women. The subject came to the laboratory after the noon meal and immediately lay down upon the couch. A single thermometer was inserted in the rectum to a depth of 7 centimeters and a second thermometer in the vagina. A thermometer was also placed in the right axilla, the subject lying on the same side to keep the cavity closed. No special bandages were used. In addition, a fourth thermometer was placed under the breast, with the breast folded over it as much as possible and kept in place by a bandage. At 4^h^ 23^m^ p. m., the thermometer was removed from under the breast and placed in the groin; the axilla was also opened at this time, and the thermometer replaced in the cavity at 4^h^ 34^m^ p. m. The curves for the rectum and the vagina had agreed remarkably well until this time, but during the change the vaginal thermometer was accidentally moved out of position and the temperature record changed to a level a little over 0.5° C. below the original. After the vaginal thermometer

had slipped out, it was unquestionably more or less covered by the labia and the fleshy portion of the leg, so that the temperature was not extremely low. The subject lay in a somewhat curled-up position after the placing of the thermometer in the groin, which helped to keep the record of the vaginal thermometer high in spite of the fact that it was not deeply inserted.

An unusually long time was required for the thermometers in the artificial cavities to reach constancy, this being unquestionably due to the imperfect closing of the cavities. The curves for these localities follow each other quite closely, but illustrate admirably the difficulty of securing proper temperature records without special precautions for perfect closure.

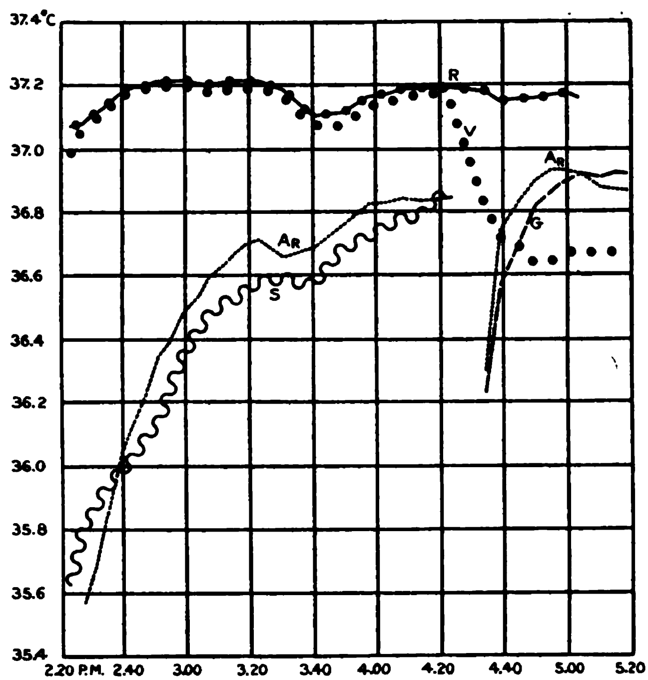


FIG. 16. Temperature curves for experiment of January 6, 1911, with Mrs. B—I.

The results of the temperature measurements are given in fig. 16. The curves for the rectal and axilla thermometers are marked in the usual way, while the curve for the vagina is designated as V, that for the thermometer placed under the breast as S, and for the thermometer in the groin as G.

Experiment of January 7, 1911, *with J. J. C.*—Both the deep and the shallow thermometers were used in the rectum, inserted to a depth of 10 centimeters and 5 centimeters respectively. Temperature records were also taken simultaneously in both axillas, the arms being folded across the chest and held in place by cloth bandages so as to insure perfect closure. The subject sat in a chair during the experiment and was very sleepy. At 12^h 09^m p. m., both axilla thermometers were removed so as to give more freedom of movement. Between 12^h 16^m p. m. and 12^h 36^m p. m. the subject ate a dinner consisting

of steak, rolls, and coffee. At 12^{h} 57^{m} p. m. he changed to a more comfortable lounging chair and the axilla thermometers were replaced. At 1^{h} 35^{m} p. m. he put his feet up on another chair.

The occasional fluctuations noted in the curve for the shallow rectal thermometer were probably due to the fact that the thermometer was not inserted to a sufficient depth, as the observer noted that the temperature fluctuated

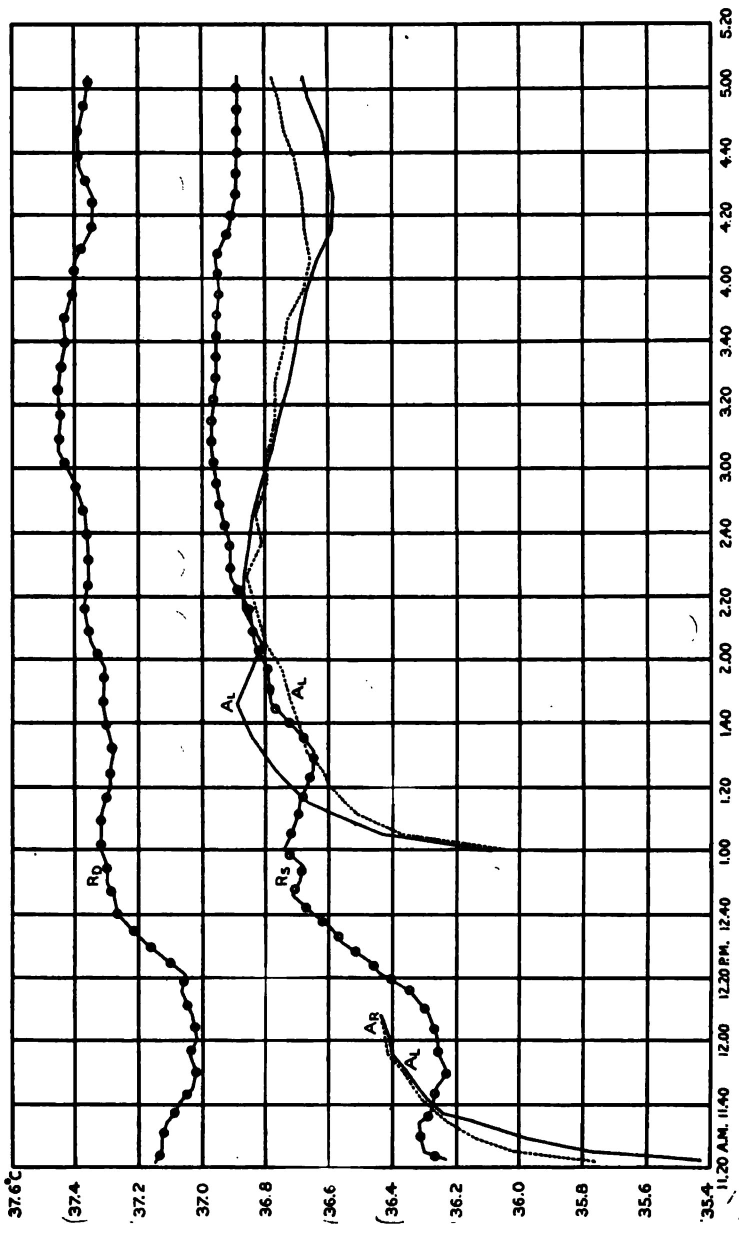
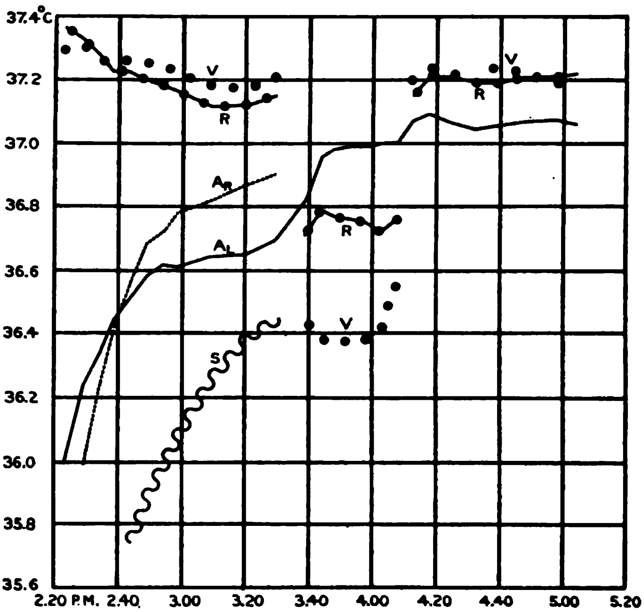


FIG. 17. Temperature curves for experiment of January 7, 1911, with J. J. C. 12.16 p. m. to 12.36 p. m., eating.

whenever the subject moved his legs. Of particular interest, however, is the fact that while the curve for the shallow rectal thermometer is much lower than that for the deeper thermometer, the two curves follow each other very closely, thus indicating simultaneously the temperature gradient previously discussed, and also a constancy in the curve of body-temperature at different parts of the body. The temperature curves for the axillas show, first, the long time required to warm the axilla to constancy, and second, the fact that unless special precautions are taken to hold the thermometers in place and fully covered with flesh, the results will have but little value. There is a marked lack of uniformity between the temperature curves for the axillas and that for the rectal thermometer. This can be explained only by the fact that the subject was very sleepy and proper precautions were not taken to



F.ı. 13. Temperature curves for experiment of January 9, 1911, with Mrs. B—l.

insure a thorough closure of both axillas, although it is a significant fact that both the axilla temperature curves show a tendency to fall off at about the same degree of rapidity.

The results of the temperature measurements are given in fig. 17, the curves being designated in the usual manner.

Experiment of January 9, 1911, *with Mrs. B—l.*—A single thermometer was used in the rectum and another in the vagina, each being inserted to a depth of 7 centimeters. A thermometer was also used in each of the axillas and one between the breasts, which were drawn together and folded over the thermometer by means of a cloth belt. The thermometers in the artificial cavities required a long time to reach constancy, doubtless on account of the imperfect closure of the cavities. At 3^h 30^m p. m. both the thermometer in the right

axilla and the skin thermometer were removed; also, the rectal thermometer and the vaginal thermometer were each supposedly withdrawn 2 centimeters. At this time, however, the vaginal thermometer slipped out, causing a discrepancy in the records. At 4h 09m p. m. both the rectal thermometer and the vaginal thermometer were returned to their original positions, without disturbing the left axilla, and from this time on the curves agree very satisfactorily.

The results of the temperature measurements are given in fig. 18, the curves being marked as usual.

Experiment of January 11, 1911, *with J. J. C.*—This experiment was divided into three parts in order to study the rectal gradient, the effect of warming the axilla previous to inserting the thermometer also being studied. Two thermometers were used in the rectum, and one in each axilla. In the first part of the experiment, the deep thermometer was inserted in the rectum to the depth of 7 centimeters, and the shallow thermometer to the depth of 4 centimeters; in the second part, the insertions were 5.5 centimeters and 2.5 centimeters respectively; and in the last part, 3.75 centimeters and 0.75 centimeter.

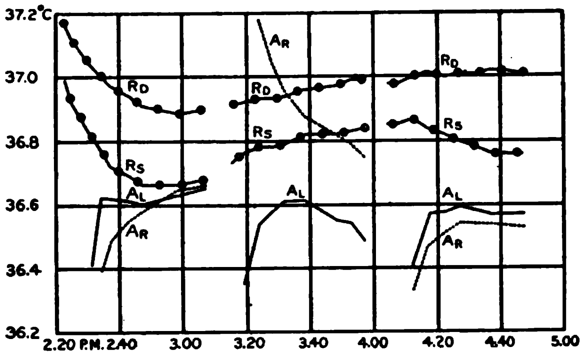


FIG. 19. Temperature curves for experiment of January 11, 1911, with J. J. C.

Previous to the first part of the experiment, a hot-water bottle, at a temperature of 40° C., was placed in the left axilla for 5 minutes, the thermometer being inserted in the right axilla, as usual without preheating. The effect of this preheating is shown by the fact that the curve for the left axilla rose more abruptly than that for the right. In the second part of the experiment, the conditions were reversed, a hot-water bottle with a temperature of 45° C. being used in the right axilla, but none in the left. Without doubt the temperature of the water used was too high, as the curve for the right axilla did not fall to the temperature level of the body for some time. In the third part of the experiment, the conditions of the first part were duplicated, the hot-water bottle at a temperature of 40° C. being placed in the left axilla, and the thermometer inserted in the right axilla without preheating the cavity. The same tendency to an abrupt rise in the curve for the left axilla was again noted, although it was not so pronounced as in the first part of the experiment. The curves for the rectal thermometers show the usual fall in temperature at the beginning of the experiment. It should be noted that the curves for the deep

and shallow rectal temperatures, by being roughly parallel but not coincident, indicate clearly the thermal gradient already discussed in considerable detail.[1] In view of this fact and that previous experiments indicate a similar gradient, a fall in temperature would be expected to follow the withdrawal of the thermometers to a less depth. This fall in temperature is not, however, shown. The discrepancy can be explained only by the fact that as the thermometers were adjusted by the subject, which involved considerable movement on his part, the statement regarding the depths of insertion is doubtless inaccurate.

The measurements of the body-temperature in the different localities are given in fig. 19, the curves being designated as usual.

Experiment of January 12, 1911, *with C. H. H.*—The deep and shallow rectal thermometers were used, also a thermometer in each axilla, the axillary thermometers being held in place by bandages. This experiment, like the preceding, was divided into three parts so that a study could be made of the rectal gradient and of the effect of preheating the axilla. In the first part of the experiment, the depth of insertion of the shallow thermometer was 6.5 centimeters, and of the deeper thermometer, 9.5 centimeters; in the second part, they were inserted 4 and 7 centimeters, respectively; and in the third part, 0.75 centimeter and 3.75 centimeters, respectively. A ho-twater bottle, at a temperature of 40° C., was placed in the left axilla 5 minutes before the experiment commenced, the right axilla not being preheated. In the second part of the experiment, the left axilla was again preheated by means of a hot-water bottle at the same temperature as before, while in the last part the hot-water bottle, at a temperature of 42.5° C., was used in the right axilla.

During the experiment, the subject apparently slept at times, but usually was lying awake and quiet. In the first part of the experiment, the left axilla had a temperature somewhat above that of the right, although the records for the two thermometers remained parallel after constancy had been obtained.

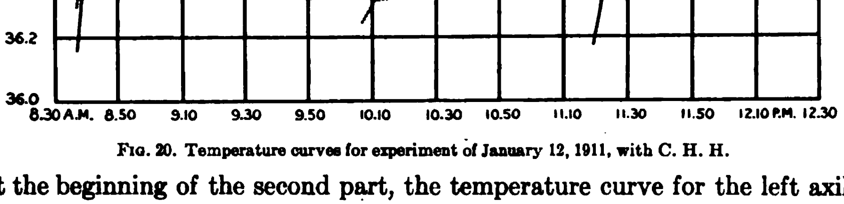


FIG. 20. Temperature curves for experiment of January 12, 1911, with C. H. H.

At the beginning of the second part, the temperature curve for the left axilla was above normal, but fell rapidly until the two axillary curves became essentially the same. In the third part of the experiment, the preheating of the

[1] See p. 35.

right axilla raised the temperature above normal and consequently this curve shows an initial fall, while the curve for the left axilla rose as usual, becoming constant in approximately 20 minutes.

It is noted that here, as in the preceding experiment, the rectal temperature curves are apparently unaffected by a change in the depth of insertion. The explanation is probably the same as before, namely, that the depth of insertion was changed by the subject himself, and therefore the depths as stated may be very seriously questioned. The fluctuations in both the rectal curves follow each other with considerable regularity, the curves being in general parallel.

The measurements of the body-temperature are given in fig. 20, the designations of the curves being as usual.

Experiment of January 12, 1911, *with F. A. R.*—In this experiment a single thermometer was used in the rectum at a depth of 10.5 centimeters; also, two thermometers were placed between the hands, one in the center of the palms, the other near the base of the second finger. To provide for the closure for the two latter thermometers, the hands were firmly clasped and tied together with bandages. The curves for the hands show at first the slowness of the cavity in approaching its final temperature; then, beginning about 2h 30m p. m., there was a decided fall in temperature, undoubtedly caused by the unconscious partial opening of the hands. The strain upon the wrists was relieved at 2h 46m p. m. by fastening a cotton strap about the arms above the elbows to prevent the hands from opening; after this the cavity gradually increased in temperature, the curves following essentially the same course. It required a long time for the cavity to attain body-temperature, and as the subject appeared to be uncomfortable, the experiment was discontinued before any opportunity was afforded to observe the parallelism of the three curves.

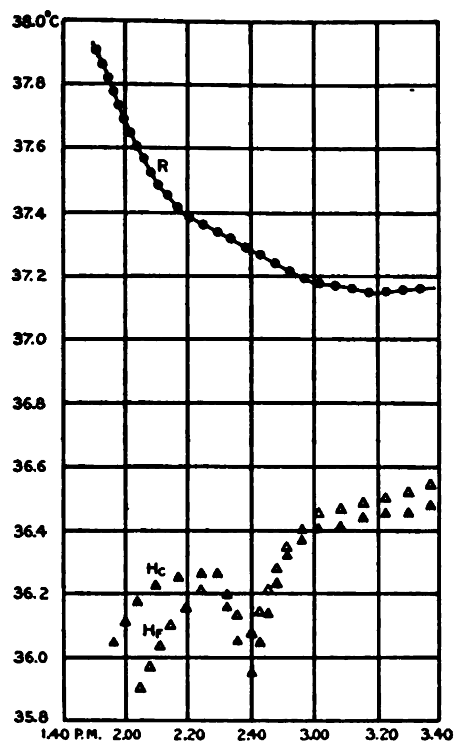


Fig. 21. Temperature curves for experiment of January 12, 1911, with F. A. R.

The measurements of the body-temperature are given in fig. 21, the designation for the rectal curve being the same as usual, those for the hands being H_c and H_f for the thermometers in the center of the palms and at the base of the second finger, respectively.

Experiment of January 13, 1911, *with V. G.*—In this experiment, a thermometer was used in the rectum at a depth of 9.5 centimeters; also, as in the previous experiment, a thermometer was placed in the center of the palms and another at the base of the second finger, with the hands clasped and tied with bandages. The space between the hands was warmed for 5 minutes before the experiment by a hot-water bottle at a temperature of 40° C.

During the experiment the subject occasionally fell asleep, but sat quietly the remainder of the time. The two thermometers in the hand gave readings which agree very well with each other, and while the parallelism with the records of the rectal thermometer is not perfect, there was a tendency for the temperature of the hand to fall as the temperature in the rectum fell. The slight rise between 3^h 19^m p. m. and 3^h 41^m p. m. indicated by the curve for the rectal thermometer is also seen in the curves for the thermometers in the hand.

The measurements for this experiment may be found represented in fig. 22, with the designations of the curves as for previous experiments.

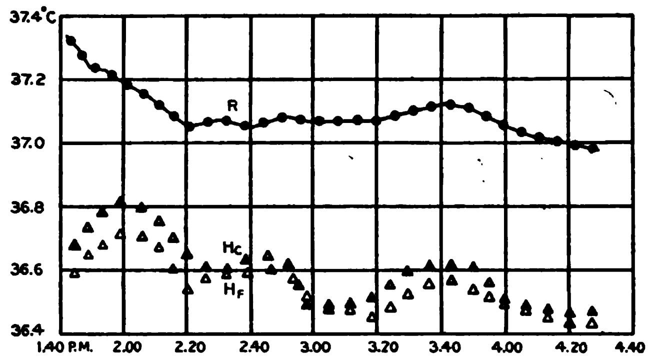


FIG. 22. Temperature curves for experiment of January 13, 1911, with V. G.

Experiment of January 14, 1911, *with C. H. H.*—In this experiment the subject sat in the chair, and both the deep and the shallow rectal thermometers were used, the former inserted to the depth of 9.5 centimeters, and the latter 6 centimeters. The temperature of the hands was taken by two thermometers as in previous experiments, the hands being clasped and bandaged as usual. Still another thermometer was placed between the crossed legs above the knees. No hot-water bottle was used.

The initial fall in the rectal temperature, noted in practically all of the experiments, is here very well marked. The curves representing the temperature in the hands remained fairly parallel throughout, but did not follow the curve of the rectal thermometer. On the other hand, the temperature of the upper leg, while requiring a very long time to reach equilibrium, followed the rectal temperature with remarkable constancy and accuracy when it had finally reached the upper level. An effort was made in other experiments to measure the body-temperature between the crossed legs, but these attempts

were unsuccessful, and the locality does not appear favorable for such observations, as its use involves much discomfort to the subject.

The records obtained in this experiment are given in fig. 23, the curves being designated as usual, that for the artificial cavity between the crossed legs being marked L.

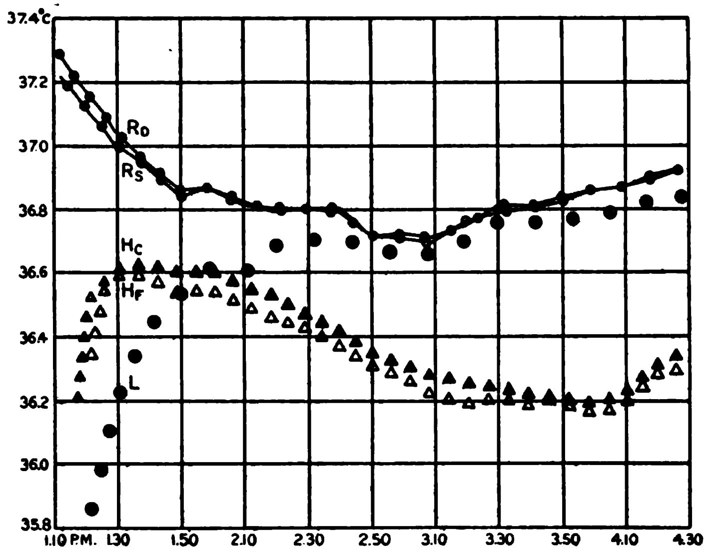


FIG. 23. Temperature curves for experiment of January 14, 1911, with C. H. H.

Experiment of January 16, 1911, *with Mrs. B—l.*—The deep and shallow thermometers were used in the rectum, inserted 7.5 centimeters and 4 centimeters respectively, and a single thermometer in the vagina at a depth of

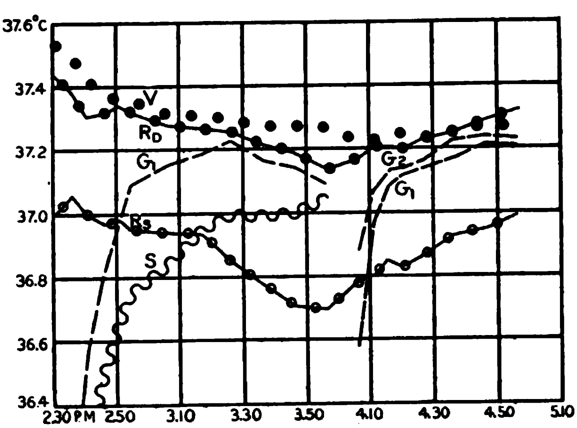


FIG. 24. Temperature curves for experiment of January 16, 1911, with Mrs. B—l.

10 centimeters. A thermometer was also placed in the left groin. At the beginning of the experiment a thermometer was strapped between the arm and the breast, but the temperature for this locality was very slow in reaching

constancy and the thermometer was later removed, and two thermometers were placed side by side in the left groin.

The usual initial fall in temperature on lying down on the couch is well shown in the curves for the deep and shallow rectal thermometers and for the vaginal thermometer. The temperatures for these three localities followed one another with fair constancy throughout the whole test. The groin temperature required considerable time to reach constancy, but thereafter followed the fluctuations in the temperature of the rectum and the vagina with reasonable regularity. As will be seen by the curves, the thermometers used in the latter part of the experiment for obtaining the temperature of the groin agreed fairly well with each other, and also followed closely those of the rectum and the vagina. While the temperature indicated by the shallow rectal curve is considerably lower than that of the deep rectal curve, it is interesting to note that the parallelism of the two records is very marked.

The records for this experiment are given in fig. 24; the curves are designated in the usual manner, the curve for the thermometer between the arm and the breast being marked S, and those for the groin, G_1 and G_2.

Experiment of January 17, 1911, *with Mrs. B—l.*—In view of the parallelism shown in the previous experiment between the groin temperature and the temperatures of the rectum and the vagina, this experiment was designed to

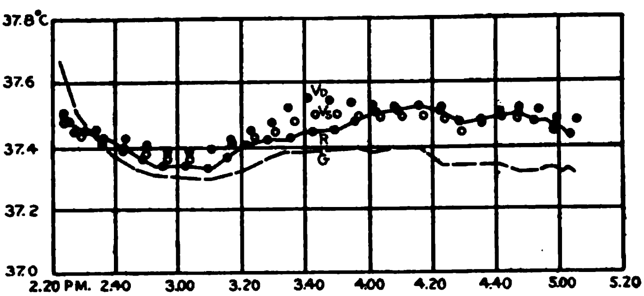


FIG. 25. Temperature curves for experiment of January 17, 1911, with Mrs. B—l.

make a comparative study of the temperatures of the groin, the deep and the shallow vagina, and the rectum, a thermometer being placed in all of these localities. In the rectum, the thermometer was inserted to a depth of 7 centimeters, while in the vagina, one thermometer was inserted to the depth of 10 centimeters, and the other to the depth of 6.5 centimeters. Before the experiment began, a hot-water bottle at a temperature of 42° to 43° C. was placed in the groin for 5 minutes. From the curves, it may be seen that the groin temperature was at first considerably higher than normal, then fell off until it reached a constant level somewhat below that of the vagina and the rectum, and thereafter followed in a general way the fluctuations of the other thermometers.

The records of the experiment may be found in fig. 25, with the curves designated as usual.

Experiment of January 20, 1911, with C. H. H.—In this experiment the subject crossed his arms on his chest, and one thermometer was placed between the lower arm and the chest, and another at the point where the arms crossed. In addition, two thermometers were used in the rectum, and one in each of the axillas, 6 thermometers in all being used. The thermal junctions were kept in position in the usual way by bandages. The locations between the crossed arms, and between the arm and the chest are particularly unfavorable for accurate records of body-temperature, as it is difficult to secure a perfect closure. The curves, however, seem to follow one another very fairly, this doubtless being due to the care exercised by the subject not to displace the thermometers. No hot-water bottles were used for preheating any of the cavities, and consequently the length of time required for the different parts to reach equilibrium is very well shown by the rise in the temperature curve at the beginning of the experiment. The usual initial fall of the deep and the shallow rectal temperatures is shown in this experiment. Between 3h 17m p. m. and 3h 22m p. m., the legs were uncovered in an attempt to produce a lowering of the temperature by exposing the skin surface, but this was without appreciable effect.

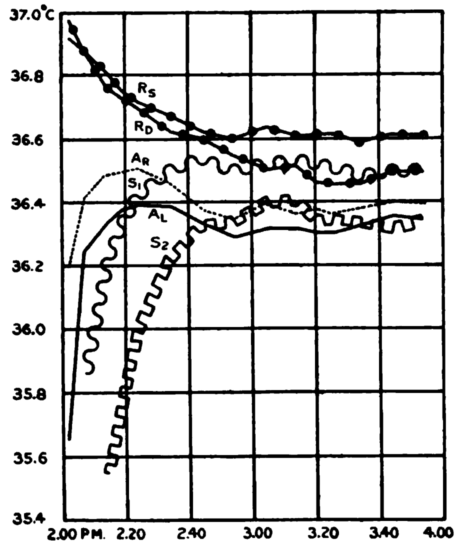


FIG. 26. Temperature curves for experiment of Jan. 20, 1911, with C. H. H.; 3.17 p. m. to 3.22 p.m., body surface exposed.

The records of the measurements are given in fig. 26, the curves being marked as usual. The curve for the thermometer between the arm and the chest is designated by S_1 and the curve for the thermometer at the point where the arms crossed by S_2.

Experiment of January 23, 1911, with C. H. H.—In this experiment the deep and shallow rectal thermometers were used to give a base line for comparison with the records of thermometers inserted in the right and the left axillas between the crossed arms, as in the previous experiment, and in the mouth. The thermometers in the rectum were inserted 12 centimeters and 8.5 centimeters respectively. The subject lay on a couch on his right side, the thermometers in the axillas being held in position by bandages as usual.

At 10h 08m a. m., the subject became uncomfortable, and lay on his back instead of on his right side. Between 10h 22m a. m. and 10h 27m a. m., the legs were uncovered to find if exposure would lower the temperature. As a matter of fact, the curves indicate a slight rise in temperature instead of a fall. The temperature in the left axilla quite closely parallels that in both the rectum and the mouth. The abnormal course of the temperature in the right axilla

and between the arms can be readily explained by the difficulty in securing a proper position on account of the discomfort of the subject. It is of interest to note that from 10h 20m a.m. to 11 a.m., the temperature between the arms (curve M) followed almost exactly that of the rectum.

The records of the measurement may be found in fig. 27, the designations of the rectal and axillary curves being as usual. The curves for the thermometers between the crossed arms and in the mouth are marked S and M, respectively.

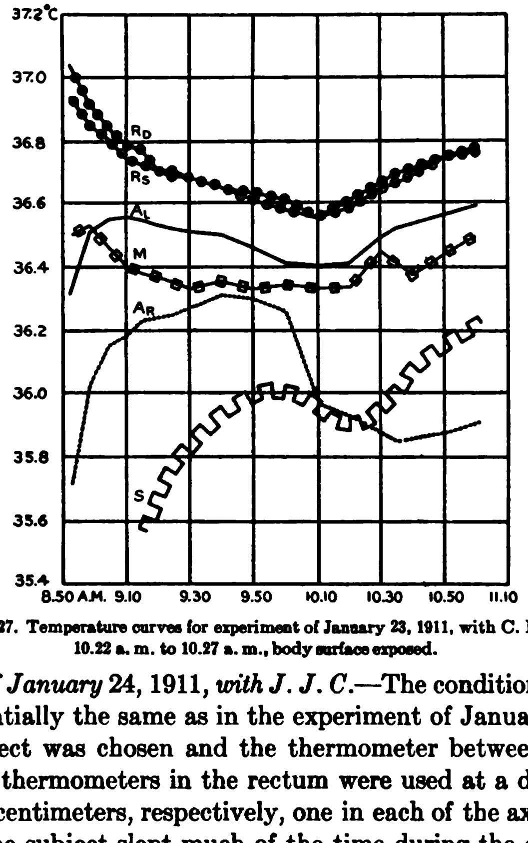


FIG. 27. Temperature curves for experiment of January 23, 1911, with C. H. H.; 10.22 a. m. to 10.27 a. m., body surface exposed.

Experiment of January 24, 1911, *with J. J. C.*—The conditions of this experiment were essentially the same as in the experiment of January 23, save that a different subject was chosen and the thermometer between the arms was omitted. Two thermometers in the rectum were used at a depth of 8 centimeters and 4.5 centimeters, respectively, one in each of the axillas, and one in the mouth. The subject slept much of the time during the experiment, and there was consequently so much trouble in securing a proper closure of the mouth that at 9h 31m a. m. the mouth thermometer was removed and replaced at 9h 44m a.m. surgeon's plaster being used to hold the lips together. At 9h 46m a.m., the subject changed his position and lay more on his side. Between 10h 59m a. m. and 11h 03m a.m., he drank 2½ cupfuls of hot coffee, the thermometers in the mouth and the axillas being removed for this purpose. The subject then turned on his side and the thermometer was replaced in the left axilla. The thermometer in the mouth was likewise replaced, surgeon's plaster being again applied. Near the end of the experiment, there were indications that the shallow rectal thermometer was closer to the anus than was reported by the subject; the wide discrepancies between the records of

the two rectal thermometers from 11h 10m a. m. to 11h 59m a. m. can hardly be explained in any other way. Similarly, at the beginning of the experiment a temperature difference of approximately 0.6° C. between the two rectal records appears to be due to the fact that the shallow rectal thermometer was not inserted to so great a depth as was supposed.

The measurements of the temperature are shown in fig. 28, the curves being marked as in previous experiments.

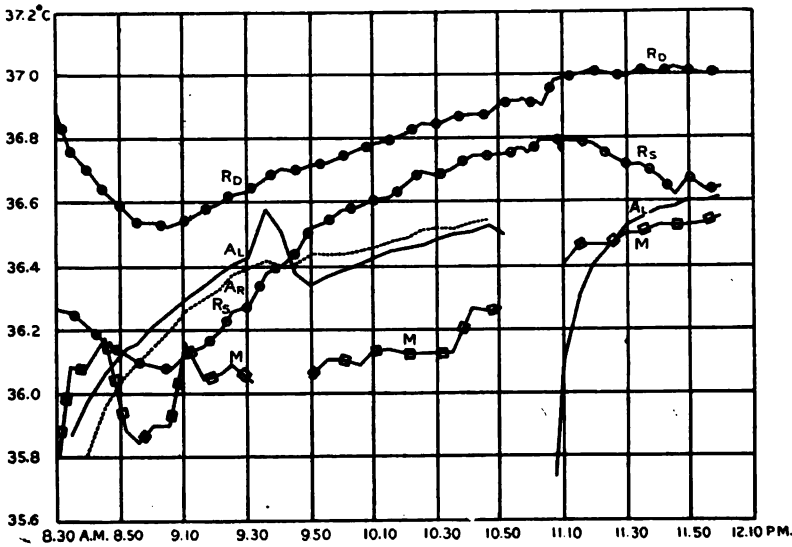


FIG. 28. Temperature curves for experiment of January 24, 1911, with J. J. C.; 10.59 a. m. to 11.03 a.m. drinking hot coffee.

Experiment of January 27, 1911, *with Mrs. B—l.*—In this and all succeeding experiments, compressed air was used to stir the water in the Dewar flask in the constant-temperature oven.

Two thermometers were used in the vagina, at a depth of 10 and 6.5 centimeters, respectively, and a thermometer in the rectum at a depth of 6 centimeters. In addition, a thermometer was placed in the groin and one in the right axilla, and intermittent observations were made in the mouth.

The curves for this experiment are interesting in that they show a period of 3 hours in which the temperature in the vagina and the rectum did not change more than approximately 0.1° C. The deep and shallow thermometers in the vagina remained within 0.07° C. of each other throughout the whole test, the records with the deep vagina thermometer being somewhat higher than those with the shallow thermometer. The rectal temperature was slightly higher than the vaginal temperature, the maximum deviation from the temperature of the deep vagina being 0.07° C. It was observed that during this experiment the rectal thermometer was embedded in feces. The thermometer in the groin required about 20 minutes to reach constancy. The curves for both the axilla and the groin temperatures follow in a general way the parallel temperatures of the deeper thermometers, although the temperature fluctua-

tions throughout the whole test were not sufficiently striking to make these records of very great value in this connection. The records of the mouth temperature are chiefly of interest as indicating the time required to warm the cavity to approximate constancy. With the mouth closed about 10 minutes prior to taking the temperature (see the curve at about 4h 29m p.m.), constancy was reached in about 8 minutes. With the mouth open for 10 minutes previous to taking the temperature, a period of over 15 minutes was required (see the curve at about 5 p.m.).

The records of body-temperature may be found in fig. 29, the curves being designated as usual.

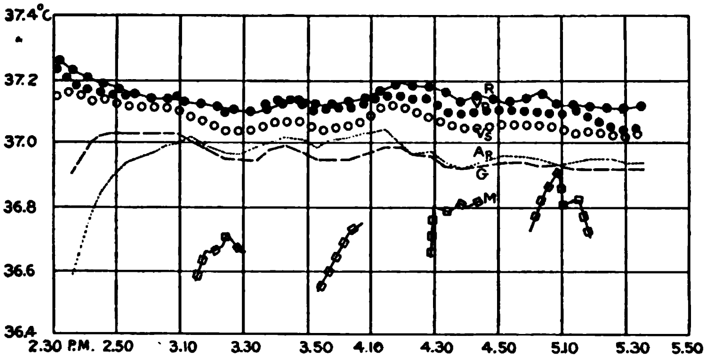


FIG. 29. Temperature curves for experiment of January 27, 1911, with Mrs. B—l.

Experiment of January 31, 1911, *with Mrs. B—l.*—In this experiment the temperature was taken in the vagina with the deep and the shallow thermometers; in the rectum with a single thermometer, also in the groin, and in either the right or the left axilla, no hot-water bottle being used for preheating the artificial cavities. An attempt was also made to secure the temperature of the mouth from time to time throughout the day, the subject being asked not to breathe through the mouth previous to the observations.

At the beginning of the experiment, the thermometer in the right axilla was not in proper position, and it was accordingly readjusted at 9h58m a. m. When this temperature had attained the maximum, however, it remained fairly constant. At 11h 58m a.m. the subject changed from the couch to a chair, and sat quietly reading, except between 1h 04m p.m. and 1h 29m p.m., when she ate a dinner consisting of steak, coffee, and potato chips. At 3h 25m p.m. she lay down again on the couch and remained either sleeping or lying quietly awake for the rest of the experiment. During the time she sat in the chair, the thermometer was placed in the left axilla, and that in the groin removed. When she again lay down on the couch, however, the thermometers were returned to their original positions.

The curves for the deep and the shallow vaginal temperatures and for the rectal temperature follow one another throughout the day with remarkable regularity for the most part. The groin temperature required a long time to reach the maximum, but thereafter the records followed those for the rectum

and the vagina. On changing the thermometer to the left axilla, considerable time was required for the temperature to reach the maximum, and this was also the case when the right axilla was again used after the subject lay down on the couch in the afternoon. The records of mouth temperature are of value only for showing the length of time required to reach the maximum; the highest point in the curve should be taken to indicate the actual temperature of the mouth, an imaginary curve joining these high points conforming to the general shape of the curves for the deep thermometers. The tendency for the curves to rise throughout the day, even when the subject lay on the couch, is characteristic of the diurnal variation in which the highest temperature is in the late afternoon.

The curves showing the body-temperature for the different localities may be found in fig. 30.

Experiment of February 3, 1911, *with Mrs. B—l.*—The deep and shallow vaginal thermometers were used in this experiment, inserted to a depth of 10 and 6.5 centimeters, respectively, also a single rectal thermometer at a depth of 8 centimeters. Thermometers were placed in the groin, in either the right or left axilla, and temperatures were taken intermittently in the mouth throughout the experiment. A hot-water bottle at a temperature of 44° C. was used in the axilla, and another with a temperature of 49° C. in the groin for about 5 minutes before the experiment, but this preheating was not so effective as usual in shortening the time required to secure constancy.

During the first part of the experiment the subject lay on the couch quietly reading. At 9^h 19^m a. m. the axilla thermometer was placed in a better position, and later (at 11^h 24^m a. m.), as the subject had been moving about considerably, it was again readjusted. At 12^h 14^m p. m., the subject changed from the couch to the chair; at the same time the thermometer was changed from the right axilla to the left axilla, which had been previously heated by means of a hot-water bottle at a temperature of 46.5° C. The temperature of the left axilla fell for the first few minutes, indicating that the preheating had raised the temperature of the cavity somewhat above the normal. From 1^h 01^m p. m. to 1^h 25^m p. m. the subject was eating dinner. At 2^h 30^m p. m. she lay down on the couch again, a hot-water bottle at a temperature of 47° C. being placed in the groin, and another at the same temperature in the axilla. In both instances the temperature rose considerably, but apparently the maximum temperature was reached in a much shorter time than in the earlier portion of the test. At 3^h 01^m p. m., the lips were fastened together with surgeon's plaster in order to keep the mouth thermometer in place for continuous observation. The subject was asleep and moved about somewhat. At 4^h 24^m p. m. she was asked to keep the mouth tightly closed. Finally the thermometer was removed from the mouth at 4^h 56^m p. m. and reinserted without the use of plaster at 5^h 19^m p. m. A higher temperature was then observed in this locality, which may have been due to a better closure of the mouth after the rest in the interval when the thermometer was not in position.

The peculiar feature of the curves in this experiment is the general uniformity of the records for the deep and the shallow vaginal thermometers and the rectal

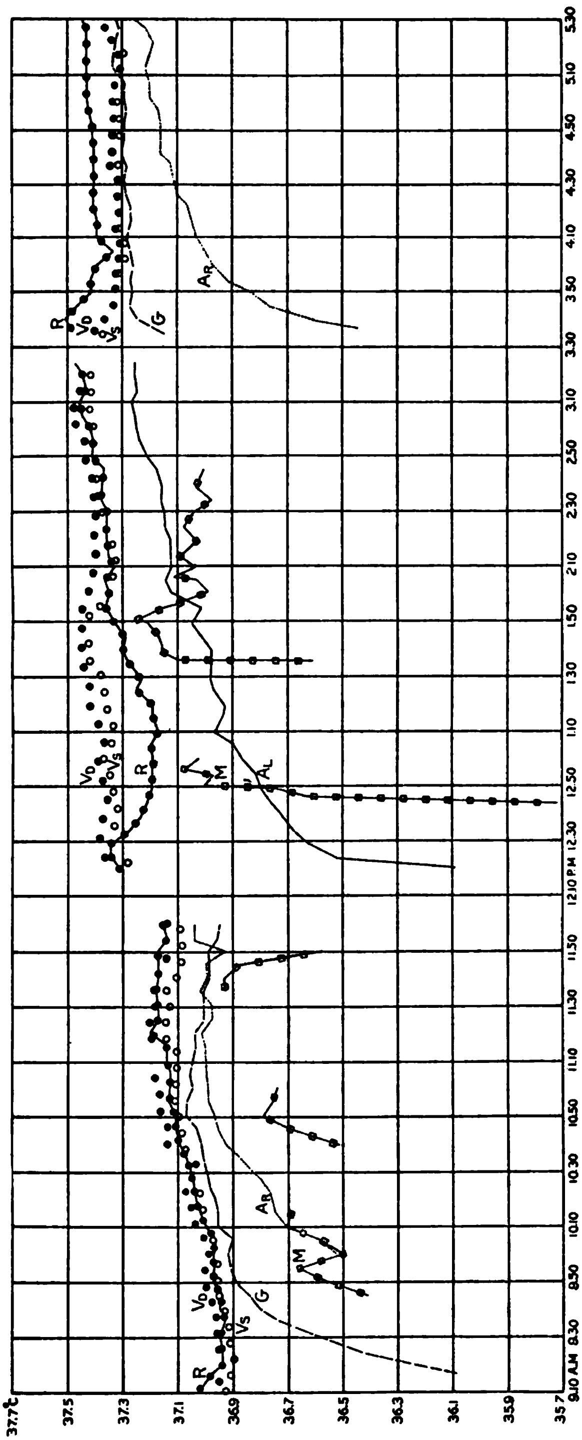


FIG. 30. Temperature curves for experiment of January 31, 1911, with Mrs. B—l. 1.04 p. m. to 1.24 p. m., eating.

thermometer, with the single exception of the record for the shallow vaginal thermometer between 2 p. m. and 2^h 30^m p. m. It would appear as if the thermometers in the vagina had been displaced during this interval, and that the shallow thermometer had slipped out of the cavity. The groin temperature followed with considerable regularity the temperature indicated by the other thermometers, while the inequalities of the axillary temperature in the early part of the experiment may be accounted for by the restless movements of the subject. The great irregularities in the temperature of the mouth accentuate the undesirability of this locality for such observations.

The curves showing the records of body-temperature may be found in fig. 31.

Experiment of February 6–7, 1911, *with Mrs. B—l.*—This experiment was planned to continue for 24 hours, in order to secure the total diurnal variation. The subject was lying on a couch during the whole experiment except when sitting in a chair between 11^h 59^m a. m. and 2^h 10^m p. m., and 5^h 24^m p. m. and 11^h 19^m p. m. A single thermometer was inserted in the rectum at a depth of 8 centimeters, and both deep and shallow thermometers in the vagina at a depth of 10 centimeters and 6.5 centimeters respectively. While the subject lay on the couch, temperature observations were made in the right axilla and in the groin. During the time the subject sat in the chair, the groin observations were discontinued, and the axillary temperature was taken in the left axilla instead of the right. Observations of the mouth temperature were made intermittently.

At the beginning of the experiment the groin and axilla were warmed by means of hot-water bottles at a temperature of 45° C. The temperature of the groin reached the maximum very shortly, but the temperature of the axilla required a long time to acquire constancy. An abnormal and wholly inexplicable rise in axillary temperature was noted, beginning at 10^h 39^m a. m. When the subject changed from the couch to the chair at 11^h 59^m a. m., the groin temperature records were discontinued and the temperature was taken in the left axilla instead of the right, so that the subject could use the right hand in eating. Before inserting the thermometer, the left axilla was heated with a hot-water bottle, at a temperature of 47° C., but gave very unsatisfactory results at first. The subject was asked to readjust the thermometer at 12^h 59^m p. m., and the results thereafter were much more uniform. Between 1^h 07^m p. m. and 1^h 32^m p. m. she ate her dinner, and at 2^h 12^m p. m., she returned to the couch. The groin and axilla were heated with hot-water bottles at a temperature of 47° C. before the thermometers were inserted, and the temperature of the groin rose considerably above even that of the rectum, cooling again rapidly to a constant temperature. The axillary temperature also quickly attained constancy. The subject was asleep between 3^h 17^m p. m. and 4^h 07^m p. m., and on waking up asked for water, drinking a half glassful at 4^h 12^m p. m. While it may have been a mere coincidence, all of the curves show a slight tendency to a lowering of the temperature after the drinking of the cold water. At 5^h 24^m p. m. the subject again changed from the couch to the chair, and the axillary temperature was taken in the left axilla, while the groin records were discontinued. During

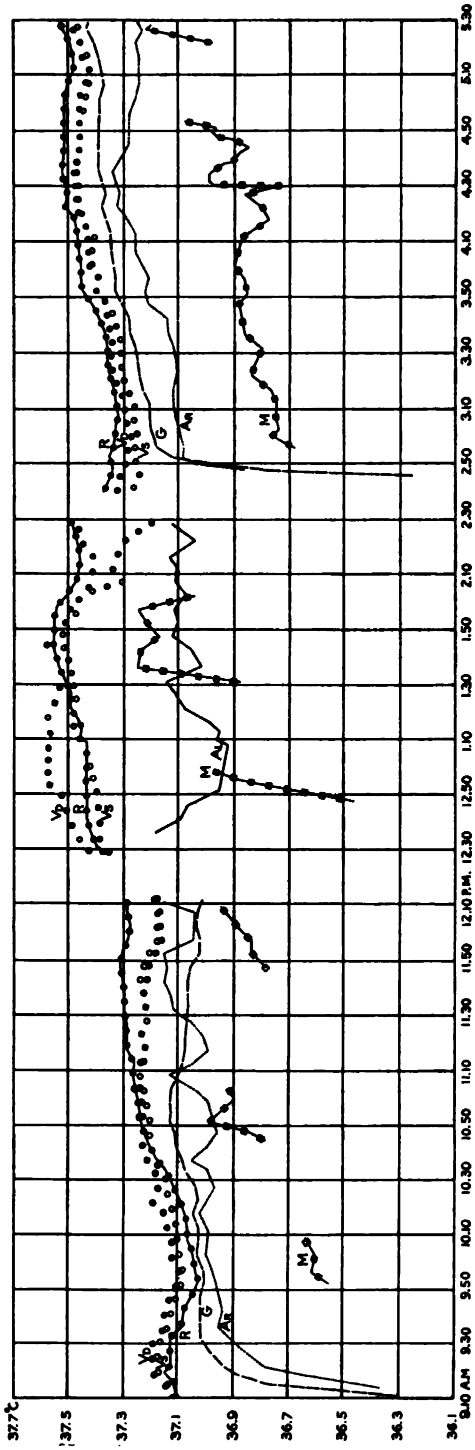


FIG. 31. Temperature curves for experiment of February 3, 1911, with Mrs. B—1. 1.01 p. m. to 1.25 p. m., eating.

this period, the subject ate her supper. While she sat in the chair, the records were so irregular that they are not given. It is possible that the thermometers were not well located, as it was noted that a difference in temperature was caused by the subject sitting forward or back in the chair. At 11^h 19^m p. m. the subject changed from the chair to the bed, and beginning at 11^h 45^m p. m. the temperature curves are again given. The groin and right axilla were heated by means of a hot-water bottle at a temperature of 47° C. The groin temperature was noticeably affected by the preheating and rapidly attained constancy, but the temperature in the right axilla required the usual 20 minutes to reach a constant level. The subject lay very quietly the first of the night, and the temperature curves fell off in accordance with the general diurnal variation. From 1^h 30^m a. m. to 2 a. m. she moved about considerably, and also between 3 a. m. and 3^h 27^m a. m. At 3^h 27^m a. m. the subject was told that she need not keep the groin closed, and this temperature record was discontinued until 4^h 12^m a. m. She reported that she had slept at times. The subject moved more or less until about 5 o'clock, but she was very quiet from 5 a. m. until 5^h 30^m a. m. Later she moved somewhat and at 6^h 46^m a. m. asked several questions. The groin and axilla thermometers were removed at 7^h 14^m a. m., and the deep and the shallow vaginal thermometers at 7^h 52^m a. m. At 8 a. m. the thermometer was replaced in the groin, the groin and rectal temperatures being recorded continuously thereafter. The subject ate breakfast between 8^h 15^m a. m. and 8^h 39^m a. m., and from that time until the end of the experiment, at 9^h 27^m a. m., she was awake, talking and reading.

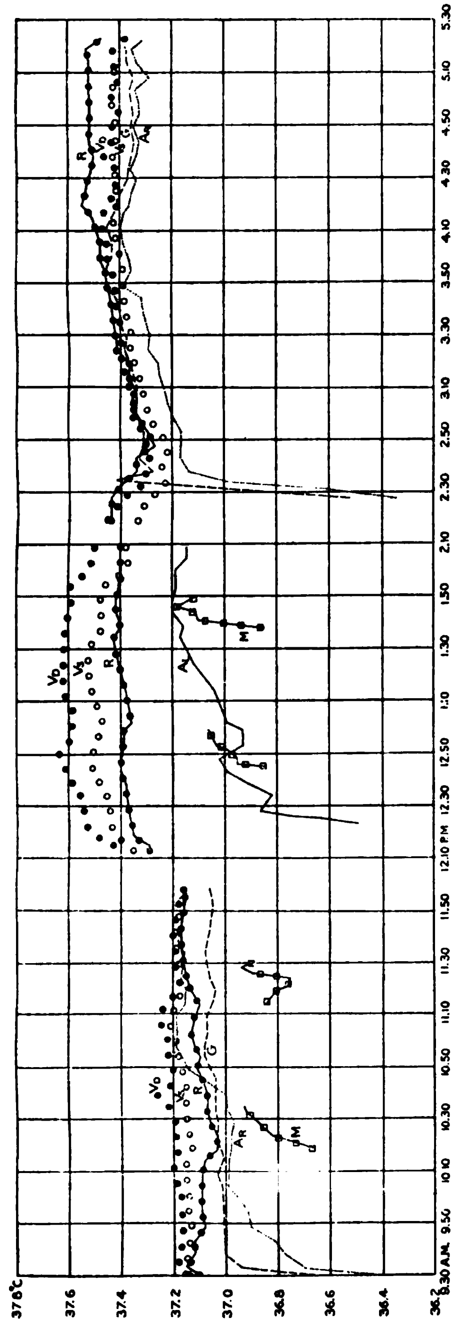
While the groin required considerable time to reach a constant temperature, except when preheated, when the body-temperature had finally been acquired the records followed with remarkable regularity those for the rectum and the vagina. The temperature of the axilla varied considerably and does not show the parallelism which would be expected, this parallelism evidently depending upon the accuracy and constancy with which the axilla is closed, thus accentuating very sharply the fact that the groin is on the whole a much better locality than the axilla for taking body-temperatures. The temperature observations made in the mouth show their usual irregularity, although a curve drawn through the maximal readings would follow the curves for the rectum and the vagina.

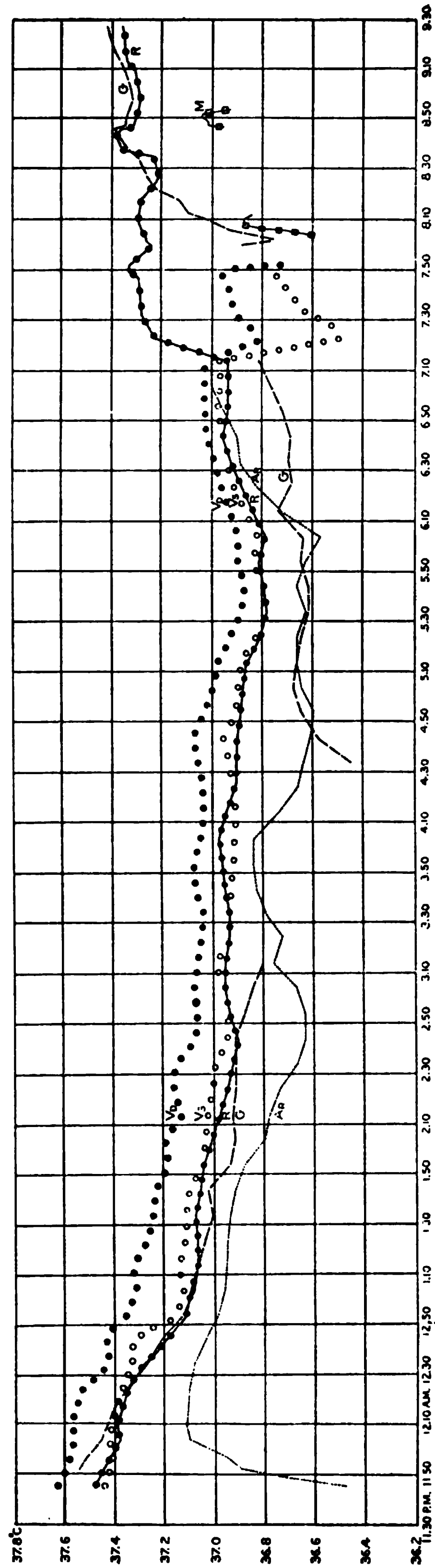
The curves showing the records of body-temperature may be found in fig. 32.

Experiment of February 27, 1911, *with J. J. C.*—In this experiment the deep and shallow thermometers were used in the rectum at depths of 9.5 and 6 centimeters respectively, and a thermometer in the left axilla. A thermometer was also inserted in the mouth and held there continuously.

During the experiment the subject sat in a chair, sometimes awake and reading and sometimes apparently asleep. At 9^h 23^m a. m. he drank some cold water. He changed his position in the chair at 10^h 33^m a. m., and the axilla thermometer was also readjusted at this time. At 11^h 16^m a. m. the left shoulder became uncovered, and at 11^h 22^m a. m. the subject removed his feet from the couch on which he had been resting them. From 12^h 21^m

FIG. 32. Temperature curves for experiment of February 6-7, 1911, with Mrs. B—I. 1.07 p. m. to 1 32 p. m., eating; 4.12 p. m., drinking water; 8.15 a. m. to 8.39 a. m., eating.





p. m. to 12h 38m p. m. he was eating, the thermometers in the mouth and in the axilla being removed during this time. Before reinserting the thermometer in the left axilla, the cavity was heated by a hot-water bottle at a temperature

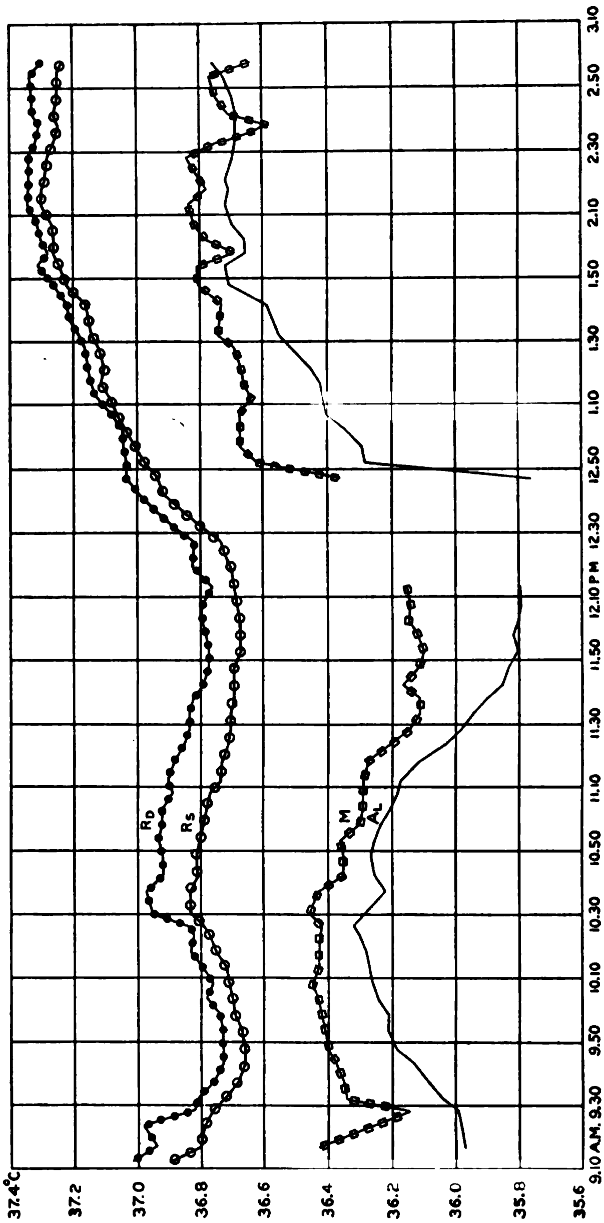


FIG. 33. Temperature curves for experiment of February 27, 1911, with J. J. C. 9.23 a. m., drinking water; 12.21 p. m. to 12.38 p. m., eating.

of 40° C.; this resulted in a rapid rise to constancy. Toward the end of the experiment the subject became very tired and uncomfortable, and at 2h 14m p. m. rested his feet on the couch again.

The general tendency toward parallelism of all of these curves is rather striking; nevertheless, the temperature of the mouth exhibits considerable fluctuation from time to time, and the temperature of the left axilla falls off more rapidly between $11^h\ 18^m$ a. m. and $11^h\ 48^m$ a. m. than do either the deep or the shallow rectal temperatures, these differences being more marked than in most of the experiments. The rapidity with which the temperature of the left axilla came to constancy after the use of the hot-water bottle at $12^h\ 47^m$ p. m. is also noticeable.

The measurements of the body-temperature are shown in fig. 33.

Experiment of March 1, 1911, *with C. H. H.*—The deep and shallow rectal thermometers were used in this experiment, with an insertion of 12 and 8.5 centimeters, respectively. A thermometer was also used in the left axilla, and one in the mouth. This experiment was designed to duplicate more or less the experimental conditions of the study made with J. J. C. on February 27. The mouth temperature was not taken continuously, however. A hot-water bottle at a temperature of 43° C. was used in the left axilla. The subject was eating between $12^h\ 37^m$ p. m. and $1^h\ 04^m$ p. m.; at $1^h\ 05^m$ p. m. he changed the position of his feet, resting them on a stool instead of on the couch.

The parallelism of the curves is very striking in all instances, the curve for the axilla, although showing a lower temperature, following the curves for the rectal temperature very satisfactorily.

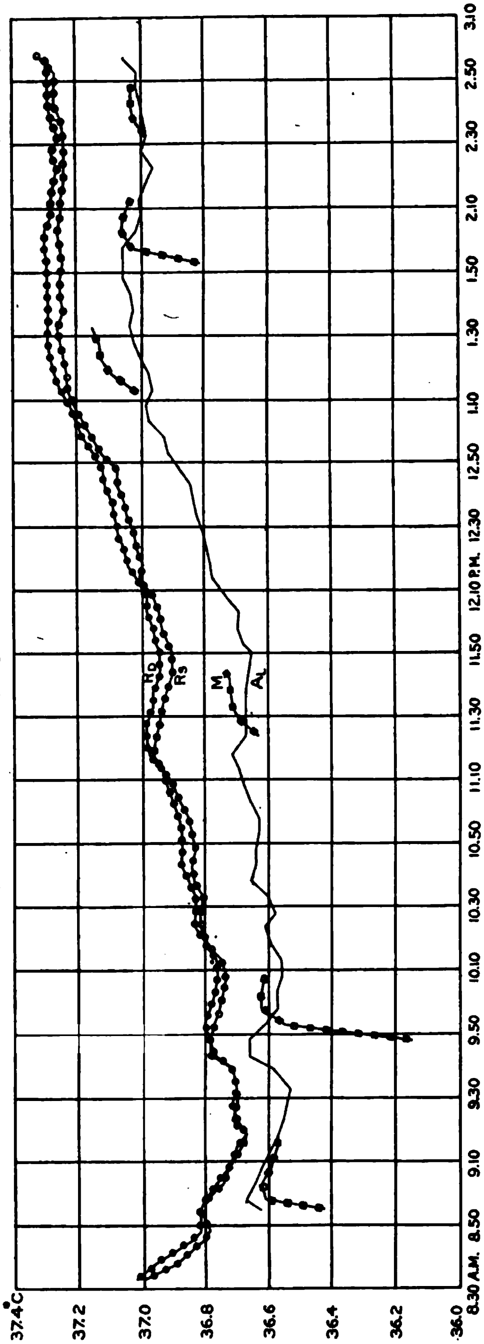


FIG. 34. Temperature curves for experiment of March 1, 1911, with C. H. H. 12.37 p. m. to 1.04 p. m., eating.

The measurements of the body-temperature may be found in fig. 34.

Experiment of March 2, 1911, *with F. A. R.*—The deep and shallow rectal thermometers were used, with an insertion of 12 centimeters and 8.5 centimeters respectively, and two thermometers in the hand, one in the center of the palms and one at the base of the second finger, the cavity between the hands having been previously heated with a hot-water bottle at a temperature of 42° C. Intermittent observations were also made of the mouth temperature. As in previous experiments, the hands were closely clasped, tied with cloth bandages, and covered with a pile of loose pieces of cloth. The arms were bound together above the elbows, as usual, to prevent the spreading apart of the wrists. At 8^h 58^m a. m. one of the hand thermal junctions was inserted a little farther toward the center of the hand. To test the effect of hot and cold drinks, the subject was given cold water at 9^h 48^m a. m. and a cupful of hot coffee at 11^h 08^m a. m.

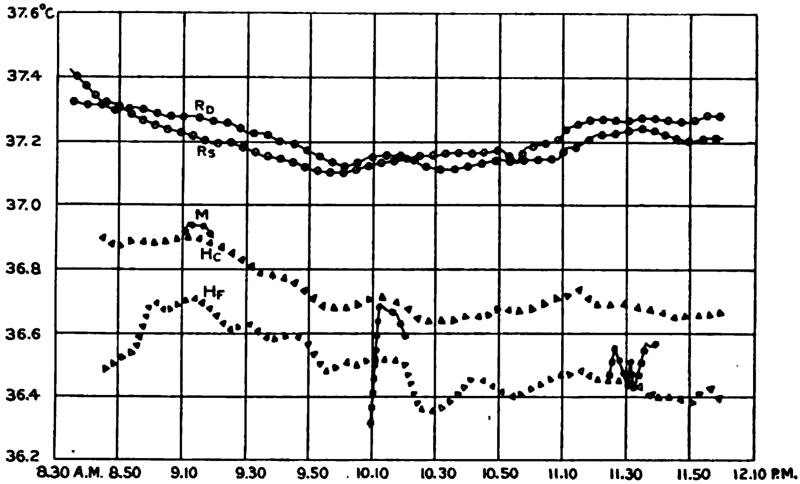


FIG. 35. Temperature curves for experiment of March 2, 1911, with F. A. R. 9.48 a. m., drinking cold water; 11.08 a. m., drinking hot coffee.

In a general way the curve for the thermometer in the middle of the hand follows the curve for the rectal thermometer, although in the latter part of the experiment the rise in temperature is not so noticeable as in the curve for the rectal thermometer. While the temperature curve for the thermometer at the base of the second finger shows wide variations, nevertheless the general tendency is not far from that shown in the curve for the thermometer in the middle of the palms. The temperatures taken in the mouth are very irregular and it is impossible to draw any deductions from the observations in this cavity. Just after taking hot coffee, a slight rise may be noted in all of the temperature curves, but the cold water appeared to have no effect.

The curves showing the measurement of the body-temperature may be found in fig. 35.

Experiment of March 3, 1911, *with F. G. B.*—In this experiment, the shallow and deep rectal thermometers were used, a thermometer in the left axilla, and one in the mouth. Before inserting the thermometer in the left axilla,

the cavity was heated by means of a hot-water bottle at 42° C. The subject sat in a chair throughout the experiment. From 2h 55m p. m. until 3h 23m p.m., he endeavored by muscular activity to stimulate a rise in temperature; he moved his legs and arms and exercised with a stool, lifting it, holding it at arm's length, and raising and lowering it above the head. He also placed a book rest on his toes, and moved it up and down. The exercise was sufficient to cause perspiration and fatigue. After the exercise, he was very quiet, closed his eyes, and tried to go to sleep. His elbows rested on the arms of the chair, and his head on his hands. At 3h 41m p. m., as the mouth thermometer was in position, some directions were written on a piece of paper. At 3h 49m p. m., 400 cubic centimeters of cold water at a temperature of 4.8° C. were taken. During the muscular work, the mouth thermometer was used, and held continuously in place until it was removed when the cold water was taken. It was then immediately replaced and allowed to come to the maximum temperature.

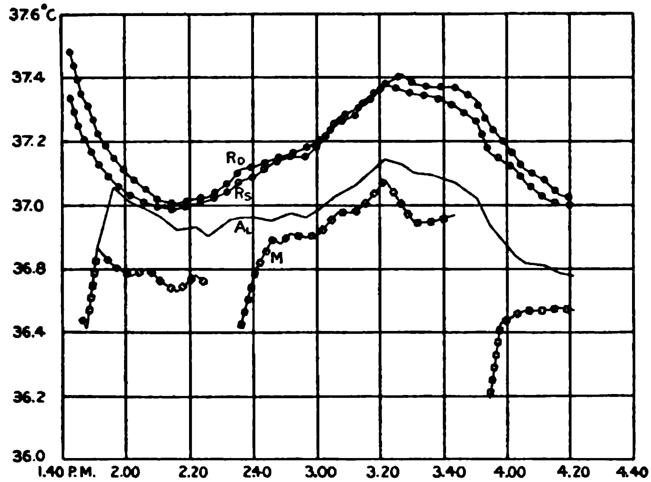


FIG. 36. Temperature curves for experiment of March 3, 1911, with F. G. B. 2.55 p. m. to 3.23 p. m., muscular exercises; 3.49 p. m., drinking cold water.

Special care was exercised by the subject to keep the mouth closed and to breathe only through the nose, so as to keep the mouth temperature as nearly constant as possible. Care was also taken not to disturb the position of the axillary thermometer. The curves for this experiment show remarkably well the uniformity between the deep and the shallow rectal temperatures, the temperature in the left axilla, and that in the mouth. The fluctuations during the muscular exercise, the succeeding quiet condition, and the taking of the cold water were almost exactly equal in all the curves and were clearly defined. As would be expected, the muscular exercise produced a rise in temperature, while the subsequent quiet condition and the taking of cold water evidently caused a lowering of the temperature.

The curves showing the body-temperature measurements for the different localities may be found in fig. 36.

Experiment of March 10, 1911, *with J. J. C.*—The deep and the shallow rectal thermometers were used at a depth of 15 centimeters and 11.5 centimeters, respectively. A thermometer was also placed in the left axilla, this cavity having been previously heated by a hot-water bottle at a temperature of 42.5° C., and intermittent observations were also taken in the mouth. The influence of muscular activity was studied in this experiment, and beginning at 3h 26m p. m. the subject exercised quite vigorously. This activity appeared to tire him, as he breathed heavily and perspired freely. During the exercise he was more or less exposed, as he wore a blanket over his shoulders instead of a sweater. At 3h 49m p. m. he stopped exercising and became quiet. For

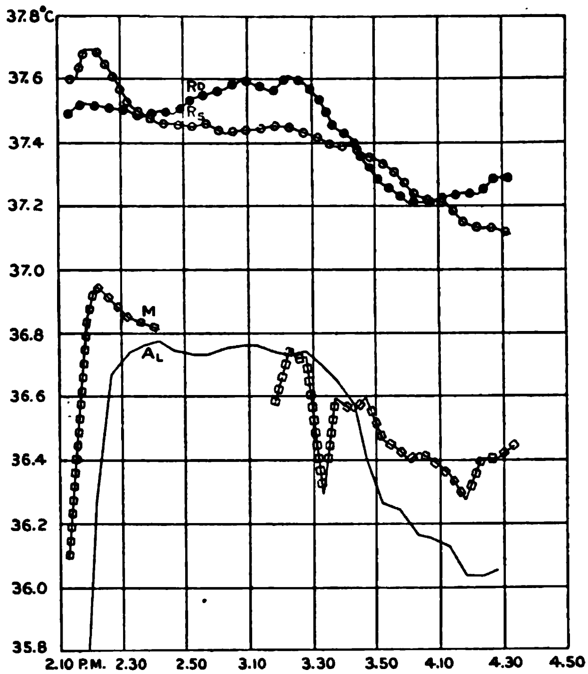


FIG. 37. Temperature curves for experiment of March 10, 1911, with J. J. C. 3.26 p. m. to 3.49 p. m., muscular exercise.

some unaccountable reason there was not a very close parallelism between the two rectal records, although all of the curves show a general tendency toward parallelism, especially the curves of the rectal and the axillary temperatures. The muscular exercise did not produce a rise in the temperature; while this is not easy to explain, it may have been due to the fact that the surface of the skin was more exposed during the exercise than when the subject was quiet, causing a tendency to cool the surface.

The curves showing the measurements of the body-temperature in the different localities may be found in fig. 37.

Experiment of March 13, 1911, *with F. A. R.*—In this experiment both deep and shallow rectal temperatures were taken, also the temperature of the left

axilla, and occasionally the temperature of the mouth. The two rectal thermometers were inserted at a depth of 10 and 6.5 centimeters respectively. The axilla was preheated by means of a hot-water bottle at a temperature of 42° C., which caused the subject to perspire; during the experiment the bandage holding the axilla thermometer loosened. In previous experiments it had been noted that the rectal temperatures usually fell at the beginning of an experiment, which would indicate that the temperature when the subject was active before the experiment was higher than after he became quiet. For this reason it was decided to take the mouth temperature at the very beginning of the experiment. If the curves indicating the mouth and rectal temperatures

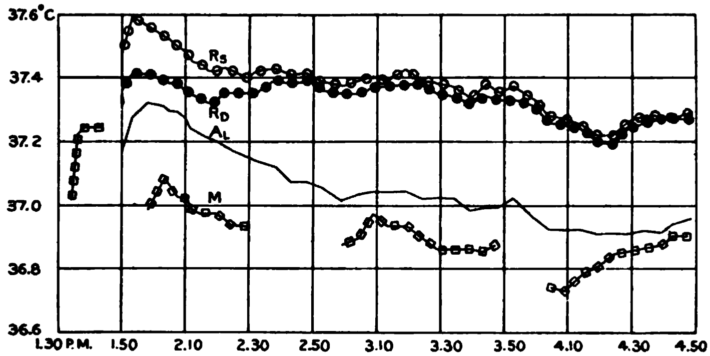


FIG. 38. Temperature curves for experiment of March 13, 1911, with F. A. R. 3.02 p. m. to about 3.50 p. m., muscular exercise; 3.50 p. m., drinking cold water.

are to be parallel, this first observation of the mouth temperature should be very high, and this was found to be actually the case. At $3^h 02^m$ p.m., the subject began to exercise by lifting a stool, and at $3^h 32^m$ p.m. he was still exercising but not working very hard. At $3^h 50^m$ p.m., just after he had stopped exercising, he drank a glass of cold water at a temperature of 10° C. A subsequent fall in temperature of almost 0.2° C. was noted, which may have been due in part to the influence of the cold water. The temperature curves for this experiment were in general parallel, the curves for the temperatures of the mouth and the rectum being more nearly parallel than usual.

The curves showing the measurement of the body-temperature in the different localities may be found in fig. 38.

CONCLUSIONS.

From this series of temperature observations made on a number of different subjects, certain definite conclusions have been drawn:

1. When two thermometers are placed in one internal cavity at not less than 6 centimeters deep, the temperature curves are parallel and approximately equal. This is shown in figs. 15, 20, 23, 25, 27, 29, 30, 31, 32, 33, 34, 35, 36, and 38, but certain abnormalities not easily explainable are seen in figs. 26 and 37.

2. When two thermometers are placed in one internal cavity and the distance between them is 3.5 centimeters, one being within 5 centimeters of the surface of the body, the curves obtained are parallel, but not equal in value, thus indicating a temperature gradient. See figs. 17, 19, 24, and 28.

3. Thermometers placed in the rectum and the vagina, at depths of at least 6 centimeters, show curves that are parallel and approximately equal. See figs. 16, 18, 24, 25, 29, 30, 31, and 32.

4. Thermometers in the right and left axillas give curves that are parallel, showing approximately equal temperatures. This is indicated in figs. 15, 17, and a part of 19, also in 20 and 26. Exceptions to this are shown in figs. 18, 27, and 28, but in considering these exceptions one must not lose sight of the fact that it is very difficult to secure constant and well-closed axillas undisturbed by body movements; we have every reason to believe that the conflicting results in these three curves are due to misplaced thermometers.

5. Two thermometers placed in the groin give results that are parallel and approximately equal. This is shown in fig. 24.

6. Two thermometers placed in the hand give results that are equal and parallel. See figs. 21, 22, and 23. In fig. 35, the curves are parallel but not equal, indicating a slight gradient.

7. The use of the hot-water bottle hastens the warming-up of such artificial cavities in the body as the axilla, groin, and hand. This fact is shown in figs. 19, 20, and 22, and in parts of 31, 32, and 33, also in 34, 35, 36, 37, and 38.

8. When lying on a couch after the slight muscular work involved in coming to the laboratory and moving about before the experiment, there is usually an initial fall of internal temperature. This is clearly evident in figs. 15, 19, 20, 21, 22, 23, 24, 26, 27, 28, 33, 34, 36, and 37, but not so well shown in figs. 17, 18, 25, 29, 30, and 35, and is entirely absent in figs. 16, 31, 32, and 38.

9. Temperatures taken in the mouth are in general extremely irregular and unsatisfactory, as may be seen in figs. 28, 29, 30, part of 31, and 32, also in fig. 35. Nevertheless fair results are shown in figs. 27, 33, and 34, and very satisfactory results in figs. 36 and 38.

10. The effect of eating a meal tends to increase somewhat the temperature of the body. See figs. 17, 30, 31, 32, 33, and 34.

11. On exposing portions of the skin under the conditions of the experiments here made, no effect on body-temperature was apparent in figs. 26 and 27.

12. On drinking hot coffee, the body temperature was very slightly increased. This is shown in figs. 28 and 35.

13. Drinking cold water had a tendency to lower the body-temperature. See figs. 36 and 38. This effect was not evident in the experiment represented by fig. 35, however.

14. Muscular exercise produced a marked increase in body-temperature in at least one experiment (see fig. 36), but was without effect in others (see figs. 37 and 38). Of significance was the fact that while obtaining the data for fig. 37, the skin of the subject was more or less exposed to the air.

15. The internal temperature of the body and that of the axilla, breast, groin, hand, arm, and mouth, have a tendency toward parallelism. This is evident in practically all of the curves, but is especially well shown for the internal temperature and the axilla in figs. 20, 27, 33, 34, 36, and 38, although in fig. 27 this is not true of the right axilla for reasons previously explained. The parallelism is also shown for the internal temperature and the groin in figs. 24, 25, and 31; for the internal temperature and the mouth in figs. 27, 33, 34, 36, and 38; and for the internal temperature and the upper leg in fig. 23.

Finally, it can be stated that an examination of all the results obtained shows in the temperature curves a remarkable trend toward parallelism, a parallelism that would be exact, there is every reason to believe, if the thermometers could remain in precisely the same position and if the cavities could remain absolutely constant in their closure. We feel justified, therefore, in summing up this work by stating that, aside from the skin temperature, a rise or fall in rectal temperature is accompanied by a corresponding rise or fall in temperature of all other parts of the body.

NUTRITION LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON,
Boston, Massachusetts, July, 1911.